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SCIENTIFIC OPINION

Scientific Opinion on the public health risks related to the maintenance of the cold chain during storage and transport of meat. Part 1 (meat of domestic ungulates)[1]

EFSA Panel on Biological Hazards (BIOHAZ)[2, 3]

European Food Safety Authority (EFSA), Parma, Italy

This scientific output, published on 12 June 2014, replaces the earlier version published on 27 March 2014*.

ABSTRACT

Salmonella spp., verocytotoxigenic *Escherichia coli* (VTEC), *Listeria monocytogenes* and *Yersinia enterocolitica* are the most relevant microbial pathogens when assessing the effects of beef, pork and lamb carcass chilling regimes on the potential risk to public health. Moreover, as most bacterial contamination occurs on the surface of the carcass, only the surface temperature is an appropriate indicator of bacterial growth. The growth of these four pathogens (using *E. coli* models for VTEC) during different time-temperature chilling scenarios was estimated using commercial slaughterhouse data and published predictive microbiology models. The outputs suggest it is possible to apply slaughterhouse carcass target temperatures higher than the currently mandated 7 °C throughout the carcass (including the core) in combination with different transport durations without obtaining additional bacterial growth. Combinations of maximum surface temperatures at carcass loading and maximum chilling and transport times, that result in pathogen growth equivalent or less than that obtained when carcasses are chilled to a core temperature of 7 °C in the slaughterhouse are provided.

KEY WORDS

carcass chilling, *Salmonella*, *Escherichia coli* (VTEC), *Listeria monocytogenes*, *Yersinia enterocolitica*, time-temperature integration, transport

[1] On request from the European Commission, Question No EFSA-Q-2013-00646, adopted on 6 March 2014.

[2] Panel members: Olivier Andreoletti, Dorte Lau Baggesen, Declan Bolton, Patrick Butaye, Paul Cook, Robert Davies, Pablo S. Fernandez Escamez, John Griffin, Tine Hald, Arie Havelaar, Kostas Koutsoumanis, Roland Lindqvist, James McLauchlin, Truls Nesbakken, Miguel Prieto Maradona, Antonia Ricci, Giuseppe Ru, Moez Sanaa, Marion Simmons, John Sofos and John Threlfall. Correspondence: biohaz@efsa.europa.eu

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SUMMARY

Following a request from the European Commission, the EFSA Panel on Biological Hazards (BIOHAZ) was asked to deliver a scientific opinion on whether or not it was possible to apply alternative core temperatures (higher than the current requirement of 7 °C in Regulation 853/2004) in combination with specific transport durations for meat (carcasses) of domestic ungulates after slaughter without increasing the risk associated with the growth of pathogenic microorganisms. It was also requested that the Panel recommend, if appropriate, combinations of maximum core temperatures for the loading of carcasses and maximum transport times.

To fulfil this mandate, the first stage was to establish the key parameters that affect bacterial growth on beef, pork and lamb carcasses and to identify the key pathogens that should be included in any consideration of the effect of chilling temperature on microbial growth. From the scientific literature it was established that the key determinants of growth on meat were temperature, pH and a_w, although other factors such as competition from other microorganisms might also be a factor. As viruses and parasites do not grow on meat, the most relevant pathogens are bacterial. *Salmonella* spp. and verocytotoxigenic *Escherichia coli* (VTEC) were identified as the most appropriate target organisms based on their 'high' priority ranking in the recently published EFSA opinions on meat inspection. *L. monocytogenes* and *Y. enterocolitica* were also included because of their ability to grow at chill temperatures.

Current legislation, Regulation EC 853/2004, requires that carcasses be immediately chilled after *post-mortem* inspection to ensure a temperature throughout of not more than 7 °C in the case of meat and not more than 3 °C for offal. In practice therefore, the temperature in the deepest carcass tissue (core temperature) must achieve a minimum of 7 °C. It is unclear as to why this target temperature was selected as pathogens such as *L. monocytogenes* and *Y. enterocolitica* will grow at 7 °C. The absence of a time limit by which the 7 °C core temperature must be achieved also introduces the possibility that carcasses could be held at temperatures that support the growth of pathogens such as *Salmonella* spp. and VTEC for extended periods while still complying with the legislation. More important for the mandated tasks was the focus on the temperature throughout the meat including the core, rather than exclusively on the surface temperature. As the vast majority of bacterial contamination occurs on the surface, the carcass surface temperature and not the core temperature is a key determinant of bacterial growth. *Salmonella* spp. and *Y. enterocolitica* may also colonise lymph nodes but there is no evidence to suggest that either multiply in lymphatic tissue during carcass chilling. It was therefore agreed that the carcass surface temperature should be the focus of this mandate.

Beef, pork and lamb carcasses may be chilled using air or spray chilling methods. Blast chilling may also be used for pork carcasses, where the rapid decrease in carcass temperature does not adversely affect the quality of the meat. Regulation (EC) 853/2004 mandates that the target temperatures should be achieved before transport and remain at that temperature during transport. However, in cutting rooms attached to slaughterhouses, meat may be cut and boned before chilling or after a period in a chilling room, following certain conditions. The statutory temperature limits must be maintained during cutting, boning, slicing, dicing, wrapping and packaging the meat by means of an ambient temperature of not more than 12 °C.

By modelling the growth of *Salmonella* spp., *E. coli* (*E. coli* models were used to predict the growth of verocytotoxigenic *E. coli*, VTEC), *L.* monocytogenes and *Y. enterocolitica* on the surface of beef and pork carcasses using hypothetical chilling curves it was demonstrated that it was possible to apply effective carcass chilling regimes in the slaughter plant other than those mandated by 853/2004. Furthermore, it was not essential that the chilling occurred in the slaughter plant as bacterial growth was related to the chilling along the continuum from slaughter to catering/domestic refrigeration. Transportation could therefore occur before a carcass target temperature was reached in the slaughterhouse chillers as long as the temperature continued to decrease towards that target during transportation. In order to establish combinations of maximum surface temperatures for the loading of carcasses and maximum transport times, two baseline scenarios that represent the current situation

were developed using temperature data from commercial slaughterhouses. The 'mean' baseline scenario represented a situation where carcasses remained in the slaughterhouse chill room until a core temperature of 7 °C was achieved and were then transported at a constant surface temperature of 4 °C for 48 hours. The 'worst case scenario' baseline was developed based on worst case surface temperature profiles (i.e. temperature profiles that would support most bacterial growth) obtained during chilling to a core of 7 °C followed by transportation at 7 °C for 48 hours. The growth of *Salmonella* spp., VTEC, *L. monocytogenes* and *Y. enterocolitica* achieved with these baseline scenarios was then compared with that which would be obtained if the carcass surface was chilled to 5-10 °C in combination with different transport times at surface temperatures of 5-10 °C.

The outputs of this modelling exercise suggest that for each of the four pathogens, less growth in the slaughterhouse would be obtained with the time-temperature scenarios tested as compared to both the 'mean' and 'worst case' baselines. Moreover, it is possible to develop different combinations of carcass surface target temperatures with specific transport time-temperature conditions that ensure pathogen growth is no greater than that achieved using the current chilling requirements (a core temperature of 7 °C followed by no more than 48 hours of transport).

In conclusion, surface temperature is a more relevant indicator of the effect of chilling on bacterial growth than core temperature as the majority of bacterial contamination occurs on the meat surface. *Salmonella* spp., VTEC, *L. monocytogenes* and *Y. enterocolitica* are the most relevant pathogens when evaluating the effect of chilling of meat (carcasses) from domestic ungulates on microbial growth and associated risk to the consumer. The potential public health risk increases with the growth of these pathogens which is affected by the continuum of chilling along the chill chain. It is therefore possible to apply alternative carcass chilling regimes, other than those mandated by current legislation (Regulation (EC) 853/2004) without incurring increased comparative bacterial growth. Combinations of maximum surface temperature-maximum transportation times that achieve equivalent or lower bacterial growth are provided in this document.

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BACKGROUND AS PROVIDED BY THE EUROPEAN COMMISSION

1.1 Current requirements

The maintenance of the cold chain is one of the main principles and basic requirements of EU legislation on food hygiene[4]. Raw materials, ingredients, intermediate products and finished products likely to support the growth of pathogenic micro-organisms are not to be kept at temperatures that might result in a risk to health. The cold chain must not to be interrupted.

In the case of meat (including fresh meat, meat products, minced meat and meat preparations), EU legislation lays down specific requirements for the storage and transport of meat regarding temperatures and maximum times of storage. Such requirements are:

- In the case of meat from animals other than poultry:

  a. *Post-mortem* inspection must be followed immediately by chilling in the slaughterhouse to ensure a temperature throughout the meat of not more than 3 °C for offal and 7 °C for other meat along a chilling curve that ensures a continuous decrease of the temperature. However, meat may be cut and boned during chilling in establishments attached to slaughterhouses.

  b. Meat must reach the temperature specified before transport, and remain at that temperature during transport. However, transport may also take place, if the competent authority so authorises, to enable the production of specific products, provided that it takes place in accordance with the requirements that the competent authority specifies in respect of transport from one given establishment to another, and that the meat leaves the slaughterhouse, or a cutting room on the same site as the slaughter premises, immediately and transport takes no more than two hours.

  c. The maximum storage time between slaughter and production of minced meat is no more than six days and no more than fifteen days from the slaughter of the animals in the case of boned, vacuum-packed beef and veal.

- In the case of poultry meat:

  a. After *post mortem* inspection slaughtered animals must be chilled to not more than 4 °C as soon as possible, unless the meat is cut while warm.

  b. Meat must reach a temperature of not more than 4 °C before transport, and be maintained at that temperature during transport. However, if the competent authority so authorises, livers for the production of foie-gras may be transported at a temperature of more than 4 °C, provided that such transport takes place in accordance with the requirements that the competent authority specifies in respect of transport from one given establishment to another, and that the meat leaves the slaughterhouse, or a cutting room, immediately and transport takes no more than two hours.

  c. the maximum storage time between slaughter and production of minced meat is no more than three days.

1.2 Available scientific advice and recent studies

The Belgian (AFSCA) and French (Anses) food safety agencies have issued in 2004, 2008 and 2009 opinions regarding the transport of meat that has not reached the required temperature upon leaving the slaughterhouse:

[4] Article 4(3)(d) of Regulation (EC) No 852/2004 of the European Parliament and of the Council of 29 April 2004 on the hygiene of the foodstuffs

- Avis 2004/01-"Problématique du transport de viande non complètement refroidie ('transport à chaud')":

http://www.afsca.be/home/com-sci/doc/avis04/Avis_2004-01.pdf

- Avis 31-2008-"Transport à chaud de carcasses de porcs (dossier Sci Com 2008/23)".

http://www.afsca.be/comitescientifique/avis/_documents/AVIS31-2008_FR_DOSSIER2008-23.pdf

- Avis 19-2009 Projet d'arrêté royal modifiant l'arrêté royal du 30/12/1992 relatif au transport des viandes fraîches, des produits à base de viande et des préparations de viandes (dossier Sci Com 2009/17)

http://www.afsca.be/comitescientifique/avis/_documents/AVIS19-2009_FR_DOSSIER2009-17_000.pdf

- Opinion (2008-SA-0283) of the French Food Safety Agency (AFSSA) on the transport of pig carcasses that have not reached the required temperature upon leaving the slaughterhouse.

http://www.anses.fr/sites/default/files/documents/MIC2008sa0283.pdf

In addition:

- A scientific study, enclosed with this request, carried out in France by IFIP (Institut du Porc), was submitted for the opinion of the French Food Safety Agency (Anses). The study evaluates the difference in bacterial growth induced by refrigerated transport of carcasses loaded at more than 7 °C, compared to the same carcasses remaining in cold storage. The study proposes combinations of time/temperature for the transport of such carcasses. The advice of Anses is expected by end of 2013.

- A scientific research was carried out in the UK on the public health risks of different time and temperature regimes for the period between slaughter and production of minced meat. That study (enclosed) concludes that, provided effective HACCP-based procedures are in place, the age of meat at mincing does not require a prescribed limit in days as a control for food safety and quality.

Before considering any derogation from the requirements described in 1.1, EFSA is requested to provide an opinion in relation to the public health risks as a consequence of applying flexibility in the maintenance of the cold chain during storage and transport of meat.

TERMS OF REFERENCE AS PROVIDED BY THE EUROPEAN COMMISSION

EFSA is asked to issue a scientific opinion on the public health risks as a consequence of applying flexibility in the maintenance of the cold chain during storage and transport of meat, taking into account the above mentioned studies and any other relevant scientific data. In particular, EFSA is requested:

In relation to transport of meat of domestic ungulates:

1. To assess if it is possible to apply alternative core temperatures, higher than 7 °C, in combination with specific transport durations for the transport of meat (carcasses) after the slaughter, without increasing significantly the risk linked to the microbiological growth of potentially harmful microorganisms, and

2. To recommend, if appropriate, in relation to such risk, combinations of a maximum core temperature for the loading of meat (carcasses) and a maximum time for transportation.

In relation to the production of minced meat from all species:

3. To assess the impact of the time of storage of fresh meat intended for the production of minced meat on the risk linked to the microbiological growth of potentially harmful microorganisms and

4. To recommend, if appropriate, in relation to such risk, maximum times of storage of fresh meat intended for the production of minced meat.

EFSA is requested to deliver an opinion (part 1) on the terms of reference 1 and 2 not later than March 2014, and an opinion (part 2) on the terms of reference 3 and 4 not later than July 2014.

ASSESSMENT

1. Introduction

Fresh meat is highly perishable because of its composition, therefore carcasses are chilled immediately after slaughter and dressing to limit bacterial growth and spoilage. This is achieved using advanced refrigeration methods based on air, immersion or spray systems. Regardless of the methods used, carcass refrigeration must satisfy several requirements including inhibiting microbial growth, meeting regulatory and/or hazard analysis and critical control point (HACCP) requirements and minimising weight loss while maintaining or improving eating quality. These requirements may be conflicting. For example, rapid chilling of carcasses inhibits the growth of pathogenic and spoilage organisms and reduces weight loss, which may be as high as 2% of the overall weight of the carcass (Jones and Robertson, 1988). However, rapid chilling of beef and lamb carcasses during the development of *rigor mortis* produces tougher meat that negatively impacts on eating quality. In contrast, rapid chilling of pork carcasses is essential to reduce problems associated with temperature/pH relationships and the development of pale, soft and exudative (PSE) meat (Savell et al., 2005).

Current legislation, Regulation (EC) 853/2004[5], requires that carcasses be immediately chilled after *post-mortem* inspection to ensure the temperature throughout the meat is not more than 7 °C in the case of meat and not more than 3 °C for offal. A time limit by which this must be achieved is not specified. It is unclear why 7 °C was selected as the maximum target temperature as pathogens such as *L. monocytogenes* and *Y. enterocolitica* will grow at this temperature. It is similarly unclear why the core and not the surface, where the vast majority of bacterial contamination occurs, was selected as the monitoring site. Moreover, the absence of a time limit by which this must be achieved introduces the possibility that carcasses may be held at temperatures that support the growth of pathogens such as VTEC and *Salmonella* spp. for extended periods while still complying with the legislation.

The current legislation is based on a process criterion, temperature, and mandates that this must reach no more than 7 °C throughout the carcass through a process of continuous chilling. Adding a time parameter would deliver a time-temperature process criterion which would better define the chilling process. A further improvement would introduce flexibility or time-temperature combinations that are equivalent in terms of bacterial or specific pathogen growth. Alternatively this approach could be refined to set maximum microbial growth targets (performance criteria) and allow slaughter plant operators to develop time-temperature combinations that consistently achieve these targets within the slaughterhouse chillers or using a combination of in-plant and transport chilling.

Meat must reach the current target temperature before transport and remain at that temperature during transportation. However, in cutting rooms attached to slaughterhouses meat may be cut and boned

[5] Regulation (EC) No 853/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules for food of animal origin OJ L 139, 30.4.2004, p. 55-205.

before chilling or after a waiting period in a chilling or refrigerated room, following certain conditions. The legislative temperature limits must be maintained during cutting, boning, slicing, dicing, wrapping and packaging the meat by means of an ambient temperature of not more than 12 °C. Furthermore, the transport of meat may take place for the production of specific products before reaching the temperatures indicated above, if the competent authority so authorises, provided that meat leaves the slaughterhouse immediately and the duration of transport is no more than two hours. The maximum storage time between slaughter and production of minced meat must be no more than six days and no more than fifteen days from the slaughter of the animals in the case of boned, vacuum-packed beef and veal.

The temperature limits and the requirements regarding transportation and maximum storage time between slaughter and the production of minced meat and boned, vacuum-packed beef and veal are creating problems for the meat industry. For example, for logistical reasons it might be desirable to transport carcasses before the core temperature has reached the required 7 °C. Moreover, maturation (the delay between the meat reaching the desired temperature and cutting) is used to improve tenderness and prevent muscle shortening. Although this typically takes 48 hours it may, at the request of the retailer, be extended for up to 21 days to improve flavour and texture. Under the current legislation, trimmings from these carcasses could not be used in minced meat or meat preparations as Reg. (EC) 853/2004 requires that these be prepared within 15 days of the slaughter of the animals. To satisfy these and other commercial requirements it may be possible to introduce greater flexibility into the current legislation if such changes do not adversely affect the public health risk.

This opinion investigates the impact of different chilling time-temperatures combinations in the plant and during transport on the growth of various pathogens on beef, pork and lamb as compared to the chilling regimes adhering to the current legislative requirements.

1.1. The location of bacterial pathogens on beef, pork and lamb carcasses and the implications for monitoring surface versus core temperatures

Cattle, pigs and sheep may carry a range of bacterial pathogens in their gastrointestinal tracts, which are shed in the faeces and cross-contaminate the carcass during slaughter and processing. Thus the vast majority of bacterial pathogens on carcasses occur on the surface (Buncic, 2006) and chilling immediately after *post-mortem* inspection should be designed to prevent the growth and proliferation of these bacteria. Indeed, Gill (1986) suggested that bacteria are only located on the surface of meat, a point of view supported by (Greer et al., 1994), who suggested that only the surface temperature rather than deep tissue temperature, is relevant to the safety of meat. While this concept forms the basis of some EC legislation (e.g. Reg (EC) 852/2004[6] and 2073/2005[7]), current legislation covering carcass chilling (Reg. (EC) 853/2004) focuses on the temperature throughout the meat including the core and not just the surface temperatures, making it difficult to assess the impact of different chilling regimes on bacterial growth as there is currently no practical mathematical formula that describes the relationship between the core and surface temperatures of carcasses. It could therefore be argued that future regulations should focus on carcass surface temperatures, provided pathogens either do not occur or do not grow at internal locations within the carcass. Moreover, any new regulations could introduce flexibility in terms of transportation after slaughter without incurring bacterial growth in excess of that which is obtained under current legislation.

While the majority of bacterial pathogens are only found on the surface of the carcasses, others such as *Salmonella* spp. and *Y. enterocolitica* may also be located in lymph nodes within the meat (Koohmaraie et al., 2012). Lymph nodes are distributed widely throughout the body and serve as a filter mechanism, trapping infectious agents before destruction by B-, T- and other immunity cells. However, some *Salmonella* spp. and pathogenic *Yersinia* spp. may evade the host immune response

[6] Regulation (EC) No 852/2004 of the European Parliament and of the Council of 29 April 2004 on the hygiene of foodstuffs OJ L 139, 30/04/2004, p. 1-54.
[7] Commission Regulation (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs OJ L 338, 22/12/2005, p. 1-26.

and survive in the lymph nodes in immune cells such as macrophages. The implications of contaminated lymph nodes for food safety is currently not yet assessed.

Although studies comparing microbial pathogen load on the surface versus the lymph nodes in a carcass are limited, Koohmaraie et al. (2012) reported that 96% of hide samples, 47% of carcasses, 18% of lymph nodes, 7.1% of trim and 1.7% of ground beef samples were *Salmonella*-positive in a study of 100 dairy cows. Other studies of *Salmonella* spp. in bovine lymph nodes have reported prevalence rates of 30% (Moo et al., 1980), 2 to 54% (Samuel et al., 1980), 61% (Samuel et al., 1981) and 0 to 88.2% (Haneklaus, 2013). One study, (Gragg et al., 2013) enumerated *Salmonella* spp. in bovine lymph nodes and reported that 67% harboured the pathogen at concentrations ranging from 0.1 to 1.8 $\log_{10}$ CFU/g while 33% carried at levels ranging from 1.9 to 3.8 $\log_{10}$ CFU/g. *Salmonella* spp. lymph node prevalence rates of 4 to 14% have been reported in sheep (Moo et al., 1980; Samuel et al., 1981). The former study also found *Salmonella* spp. in 8% of porcine lymph nodes. A European baseline study conducted in 2007 reported that 10.3% of lymph nodes from 19,071 pigs were *Salmonella*-positive (EFSA, 2008). In pigs, the incidence of *Salmonella* spp. may be higher in ileocaecal lymph nodes as compared to the surface of the carcass (Gomes-Neves et al., 2012). Pig lymph nodes may also carry *Y. enterocolitica*. A study of slaughter pigs by Nesbakken et al. (2003) showed that 12 of 97 submaxillary lymph nodes were positive for *Y. enterocolitica*. In the same study different loci were studied in 24 pigs. *Y. enterocolitica* was detected in two of the mesenteric lymph nodes, in three of the submaxillary lymph nodes and isolated from the surfaces of three carcasses. However, these studies did not enumerate and the significance of *Salmonella* spp. and *Y. enterocolitica* in lymphatic tissue for human illness has yet to be determined.

While these studies establish the importance of lymph nodes as a source of *Salmonella* spp. in cattle, sheep and pigs and *Y. enterocolitica* in pigs there are no published studies that have investigated the potential growth of these pathogens in lymph nodes post-*mortem*. It is therefore not possible to assess the impact of changing the chilling temperature on pathogen growth in lymph nodes.

1.2. Change of pH and water activity (a_w) of carcass during chilling

During chilling the temperature of the surface of the carcass changes as do other parameters such as pH and a_w. Temperature is the primary factor affecting bacterial survival and growth but pH and a_w may also influence the microflora. If pH and/or a_w change sufficiently during carcass chilling they should be considered when examining the effect of chilling on the carcass surface microflora (Beales, 2004).

Although specific data on the surface pH of red meat carcasses during chilling is limited, it is known that the pH of muscle is about 7.0 at slaughter thereafter decreasing to approximately 5.3-5.8. In beef carcasses, this usually occurs over an 18 to 40 hour period but the typical decline for pork is 6-12 hours (Smulders at al. 1992). McGeehin and Sheridan (1999) reported a decrease in the pH of lamb carcasses from 6.7 to 5.5 after 24 hours in the slaughterhouse chiller. Dark Firm Dry (DFD) meat can occur in all species but is most often described in beef. In cattle that are rested and not exposed to stress, muscle glycogen levels will be 0.8% to 1.0% prior to death. However, an animal exposed to various forms of long-term pre-slaughter stress significantly depletes its glycogen reserves. A depleted state of glycogen, less than approximately 0.6%, will hinder normal post-mortem pH decline. DFD meat will have a pH of 5.9-6.5, with some meat being as high as pH 6.8. DFD meat with a high pH may promote both growth of spoilage and pathogenic bacteria. Measurement of pH and application of meat on the basis of such measurements is important. Carcasses and meat with a high pH are not suitable for vacuum packaging and/or long-distance transport.

The scarce available evidence suggests that changes in the surface a_w of beef carcasses are limited during commercial chilling and do not affect bacterial survival with the exception of *Campylobacter*, which is particularly sensitive to drying (EFSA BIOHAZ Panel, 2013b). Fresh meat has an a_w which is frequently around 0.99 (ICMSF, 1998). Accordingly, a wide range of bacteria are able to survive and grow on meat and carcass surfaces. During air chilling the surface a_w of beef carcasses generally

decreases in the first 6 hours and increases between 6 and 24 hours before decreasing and reaching a steady state at about 72 hours (Prendergast et al., 2007). The extent of drying is controlled by the relative humidity (RH) of the chilling area (Prendergast and Sheridan, 2008) and carcass a_w typically ranges from 0.95 to 0.99 under commercial conditions. Although bacterial survival rates decrease with decreasing a_w (Shadbolt et al., 1999), studies by Kinsella et al. (2006) suggest the relatively minor changes obtained on beef carcasses during chilling are not sufficient to influence the survival of most bacteria on beef carcass surfaces. Although similar studies have not been undertaken with other meat species, there is no reason to expect a different outcome.

2. Approach to answering the terms of reference (TOR)

To evaluate different chilling scenarios, growth of *Salmonella* spp., VTEC, *L. monocytogenes* and *Y. enterocolitica* on the meat surface during chilling was estimated using published predictive microbiology growth models. Fixed values for model variables, e.g. pH, a_w, were used, and a lag phase before growth commenced was assumed to be absent. An overview of the approach used is shown in Figure 1 and details of the modelling are described in Chapter 6 and in Appendix A.

2.1. Approach to answering TOR 1

Bacterial contamination on carcasses is assumed to occur predominantly on the surface (see section 1.1). To address TOR 1, chilling data was obtained that measured the core and corresponding surface temperatures of the carcasses during commercial chilling. The growth of *Salmonella* spp., VTEC, *L. monocytogenes* and *Y. enterocolitica* was predicted using the carcass surface temperature profiles obtained when the carcasses were chilled to a core temperature of 7 °C.

2.2. Approach to answering TOR 2

As described in the introduction, growth and related risk is mainly related to carcass surface, not core, temperatures. However, only core temperature is defined in the legislation and there is no simple relationship between surface and core temperatures. While further investigation and access to more chilling temperature profiles might yield a mathematical formula that goes some way to describing the relationship between core and surface temperature, the development of such an equation was not possible within the timeframe of this work and with the available data. Instead, an approach predicting potential bacterial growth based only on surface temperatures was used. The approach taken was to evaluate and compare different time-temperature surface chilling curves, representing current, baseline, and alternative chilling scenarios, in terms of the estimated potential bacterial growth during chilling. Specifically the growth of *Salmonella* spp., VTEC, and *L. monocytogenes* and/or *Y. enterocolitica*, was estimated.

An additional complication is the existence of a vast number of chilling curves that achieve a continuous decrease throughout the meat to a target core temperature of 7 °C as required by Regulation (EC) 853/2004 for meat of domestic ungulates, each with associated bacterial growth. To model the growth of *Salmonella* spp., VTEC, *L. monocytogenes* and/or *Y. enterocolitica*, a baseline scenario had to be developed for each meat species that represents the current situation. Based on the requirements in the current legislation, each baseline scenario consisted of two stages; chilling in the slaughterhouse and chilling during transport (chapter 6 and Appendix A). The baseline scenario was taken to represent a situation where carcasses remain in the chilling room until the core temperature reaches 7 °C and then transported with a constant surface temperature. The time needed to reach the core temperature of 7 °C was estimated based on published data and compared with industry data. The first stage of the baseline was described by an exponential decay function developed by fitting parameters to simulated data representing the surface temperature over the estimated time required for the core to reach 7 °C. In the second stage of the baseline scenario carcasses are assumed to be transported with a surface temperature of either 7 °C or 4 °C. These temperatures are considered as 'worst-case' and 'mean' compliant surface temperatures during transport that corresponds to the core temperature regulation limit. The approaches taken to develop the baseline scenarios for the different species were slightly different due to the type and amount of input data that was available. Much data

was available for chilling of pork, whereas data on carcass surface temperatures of beef and lamb during chilling was scarce. The issue of a vast number of potential chilling curves that achieve a continuous decrease to a 7 °C core temperature target mandated in Regulation (EC) 853/2004, each associated with different amounts of bacterial growth, makes the selection of baseline scenarios somewhat arbitrary. Therefore the existence of variation was acknowledged by describing both an average and a worst-case baseline scenario. Recommendations on alternative time and temperature combinations are made based on comparisons between baseline and relevant chilling scenarios.

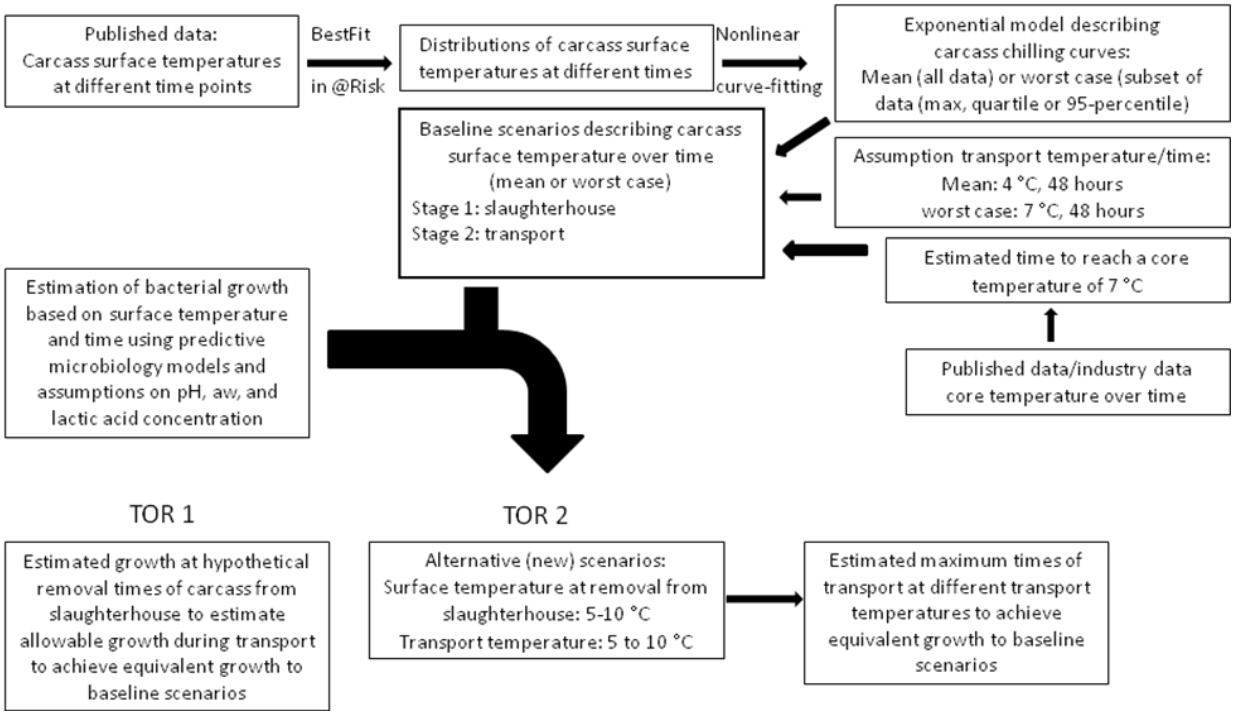

Figure 1: Approach used to answering the terms of reference (TOR)

3. Hazard identification

3.1. Bacterial hazards that may be influenced by chilling time-temperature combinations

The first step in assessing the effect of different carcass chilling time-temperature combinations on the risk to the consumer is the identification of pathogenic organisms that are meat-borne and capable of growth within the range of temperatures encountered on the surface of a carcass as it cools in the chilling room immediately after dressing. Parasitic and viral pathogens do not grow on the carcass and may therefore be excluded from any consideration of the effects of different chilling regimes on growth. *Campylobacter* spp. do not usually grow outside of their host and never at temperatures below 30˚C (Hazeleger et al., 1998). Pathogenic meat-borne bacteria such as *L. monocytogenes* and *Y. enterocolitica* may grow at temperatures as low as -2 to 4 °C while *Salmonella* spp. and VTEC may show limited growth at temperatures as low as 5 to 7 °C but rapid multiplication at 25 to 37 °C, carcass temperatures encountered early in the chilling process. The temperature, pH and a_w conditions that support the growth of these four pathogens are summarised in Table 1. Other factors such as competition from other bacteria, nutrient availability, gaseous environment, chemical composition, etc. also affect bacterial growth. These four bacterial hazards will be discussed in this chapter.

3.1.1. *Salmonella* spp.

Salmonella spp. are one of the most common and widely distributed food-borne pathogens in the EU and salmonellosis is a major cause of human bacterial enteric illness second only to campylobacteriosis. In the EU, 91,034 confirmed salmonellosis cases in humans were reported in 2012, a notification rate of 22.2 per 100,000 of the population (EFSA and ECDC, 2014). However, it

is estimated that the true incidence is 6 million cases of illness annually in the EU-27 (EFSA Panel on Biological Hazards (BIOHAZ), 2011). The most commonly reported serovars in confirmed cases of human infection in Europe are *S.* Enteritidis and *S.* Typhimurium. In 2012, these serovars accounted for 41.3% and 22.1 % of salmonellosis cases, respectively, followed by monophasic *S.* Typhimurium (7.2 %), *S.* Infantis (2.5 %), *S.* Stanley (1.4%), and *S.* Thompson (1.3%) (EFSA and ECDC, 2014). Cattle, pigs and poultry are asymptomatic carriers of these *Salmonella* serovars and there is considerable evidence that beef, pork and poultry products are major sources of human infection (EFSA Panels on Biological Hazards (BIOHAZ), on Contaminants in the Food Chain (CONTAM), and on Animal Health and Welfare (AHAW), 2011, 2012; EFSA BIOHAZ Panel, 2013b). In 2012, the distribution of food vehicles in strong-evidence outbreaks caused by *Salmonella* spp. were: 5.6% pig meat and products thereof, 2.0% bovine meat and products thereof, and 6.9% other or mixed meat and products thereof (EFSA and ECDC, 2014)

Salmonella spp. has a reported minimum growth temperature of 5ºC and an optimum temperature of 35 °C to 43 °C (James and James, 2014), a pH growth range of 4.5 to 9.0 and a minimum a_w for growth of 0.94 (de Almeida Moller, 2012) (Table 1). The observed *Salmonella* spp. prevalence on pig carcasses may decrease (Arguello et al., 2012; Botteldoorn et al., 2003; Bouvet et al., 2003; De Busser et al., 2011; Duggan et al., 2010; Oosterom et al., 1985), remain unchanged (King et al., 2012) or increase (Algino et al., 2009; Chang et al., 2003; Epling et al., 1993) during chilling and subsequent chilled storage. This apparent inconsistency may be due to a range of factors including differences in chilling performance, bacterial strains, sampling methods, etc. (Gonzales-Barron et al., 2013) but where a reduced prevalence was observed, this was attributed to the combined effects of cold shock and drying (Chang et al., 2003; Kuitche et al., 1996).

3.1.2. Verocytotoxigenic *Escherichia coli* (VTEC)

VTEC[8] are characterised by the production of verocytotoxins, so called because of their activity on Vero cells, but also referred to as shiga toxins, because of their similarity with the toxin produced by *Shigella dysenteriae*. Not all VTEC strains have been associated with human disease and there is no single or combination of marker(s) that defines a 'pathogenic' VTEC (EFSA BIOHAZ Panel, 2013a). In Europe, approximately half of all confirmed VTEC cases are associated with serogroup O157. Of the non-O157 cases, O26, O103, O145, O111, and O91 have also been commonly isolated from patients. In 2011, *E. coli* O104:H4 caused a major outbreak which resulted in 4,321 confirmed cases, including 852 cases of HUS, with 54 deaths reported in 14 EU MSs, the USA and Canada when the epidemic was declared to be over at the end of July 2011 (Karch et al., 2012). In 2012, 5,671 confirmed VTEC cases were reported in the EU with a notification rate of VTEC of 1.15 cases per 100,000 population. The most commonly reported serogroup was O157 (41.1 %), followed by O26 (12.0 %) and O91 (3.6 %) (EFSA and ECDC, 2014).

There is considerable evidence, including epidemiological, surveillance and source attribution studies, that beef is a major source of *E. coli* O157 and non-O157 VTEC (EFSA BIOHAZ Panel, 2013a). Although cattle are considered to be the most important source of human infections, VTEC are also routinely isolated from sheep and goats with reported flock prevalence of 11.6% and 13%, respectively. This and other evidence that these small ruminants may be a source of VTEC infection in humans is presented in the 'Scientific Opinion on the public health hazards to be covered by inspection of meat from sheep and goats' (EFSA BIOHAZ Panel, 2013c).

Pathogenic *E. coli*, such as VTEC, have a reported minimum growth temperature of 6-7 ºC, an optimum temperature of 35 to 42 °C (James and James, 2014), will grow between pH 4.4 and 10.0 and at a minimum a_w of 0.95 (Desmarchelier and Fegan, 2003). Inoculation studies with *E. coli* on beef carcasses stored at 10 °C showed a 1.42 log reduction in the first 24 hours on the rump while growth was observed on the neck (Prendergast and Sheridan, 2008). This was attributed to the rapid decline in surface a_w at the rump. In commercial chillers, *E. coli* counts on pig carcasses may remain unchanged or decrease during chilling (Gill et al., 2000), while *E. coli* counts on lamb carcasses decrease by up to

[8] VTEC and STEC are used synonymously

2 logs during the chilling phase (Gill and Jones, 1997). These reductions were also attributed to the drying of the carcasses.

3.1.3. *Listeria monocytogenes*

In 2012, 26 MSs reported 1,642 confirmed human cases of listeriosis, which was a 10.5 % increase compared with 2011. The EU notification rate was 0.41 cases per 100,000 population (EFSA and ECDC, 2014). *L. monocytogenes* is ubiquitous in nature and in the abattoir environment (Borch et al., 1996; Gobat and Jemmi, 1990). Listeriosis is not usually associated with fresh meat but with ready-to-eat products, in which contamination has occurred before or during processing, followed by growth during prolonged storage at refrigeration temperatures. *L. monocytogenes* has been reported on beef, pork and lamb carcasses (Sheridan et al., 1994; Nicholas, 1995; McEvoy et al., 1998). This organism grows optimally at 30 to 37 °C (James and James, 2014) and although capable of growth at -1 °C, several studies have reported a reduction in *Listeria* on beef and pork carcasses during chilling (Elmnasser et al., 2006; Moorhead and Dykes, 2004; Prendergast et al., 2007). The pH range for growth is 4.4 to 9.4 and the minimum aw supporting growth is 0.92 (ICMSF, 1996).

3.1.4. *Yersinia enterocolitica*

In recent years, *Y. enterocolitica* has been the third most common cause of bacterial food-borne disease in many European countries, with 7,017 confirmed cases in the EU in 2011 (EFSA and ECDC, 2013). The most common manifestation of *Y. enterocolitica* infection is gastroenteritis, which is usually self-limiting, resulting in diarrhoea, mild fever and abdominal pain and sometimes also reactive arthritis.

This organism infects a wide range of species, including ruminants, dogs and cats, but pigs are the main reservoir of the most common human pathogenic serogroups O:3 and O:9, and case-control studies of yersiniosis conducted in Belgium (Tauxe et al., 1987) and in Norway (Ostroff et al., 1994) have identified consumption of pork as an important risk factor for infection in humans. In the USA, case-control studies showed that household preparation of chitterlings (raw pork intestines) was associated with *Y. enterocolitica* infection in children (Jones et al., 2003; Lee et al., 1990). Further evidence of the link between pigs, pork carcasses and products is presented in the 'Scientific Opinion on the public health hazards to be covered by inspection of meat (swine) (EFSA Panels on Biological Hazards (BIOHAZ), on Contaminants in the Food Chain (CONTAM), and on Animal Health and Welfare (AHAW), 2011). *Y. enterocolitica* survives well on chilled carcasses including those subject to blast chilling (Nesbakken et al., 2008). Although these bacteria have an optimum growth temperature of 28-29 °C, they are also capable of growth at -2 ºC (James and James, 2014) and growth on meat under chilled conditions has been reported (Bari et al., 2011). However, the literature is contradictory regarding the multiplication of human pathogenic *Y. enterocolitica* in meat during conventional cold storage. According to many reports, the ability of *Y. enterocolitica* to compete with other psychrotrophic organisms normally present in food may be poor (Fukushima and Gomyoda, 1986; Schiemann, 1989; Kleinlein and Untermann, 1990). In contrast, a number of studies have shown that human pathogenic *Y. enterocolitica* is able to multiply in foods kept chilled under storage, and might even compete successfully with the micro-organisms usually found in food (Bredholt et al., 1999; Gill and Reichel, 1989; Lee et al., 1981; Lindberg and Borch, 1994; Nissen et al., 2000; Nissen et al., 2001; Stern et al., 1980). Regardless, the reported pH range for growth is 4.2 to 10.0 and the minimum a_w is 0.96 (ICMSF, 1996).

Table 1: The temperature, pH and a_w conditions that support the growth of *Salmonella* spp., VTEC, *L. monocytogenes* and *Y. enterocolitica*.

Bacteria	Minimum growth temperature (˚C)	Optimal growth temperature (˚C)	pH range for growth	Minimum a_w for growth
Salmonella spp.	5 °C[a]	35-43 °C[a]	4.5-9.0[b]	0.94[b]
VTEC	6-7 °C[a]	35-42 °C[a]	4.4-10[c]	0.95[c]
L. monocytogenes	-1 °C[a]	30-37 °C[a]	4.4-9.4[d]	0.92[d]
Y. enterocolitica	-2 °C[a]	28-29 °C[a]	4.2-10[d]	0.96[d]

a: James and James, 2014
b: Oliveira de Almeida Møller, 2012
c: Desmarchelier and Fegan, 2003
d: ICMSF, 1996

4. Red meat chilling, transportation and further processing

Beef, pork, and lamb carcasses must be chilled immediately after slaughter and dressing to ensure quality and safety. A summary flow diagram for chilling, transportation and further processing of red meat carcasses is provided in Figure 2. The first 24 hours *post-mortem* are critical in determining the quality and palatability of red meat. The biochemical processes and structural changes that occur in this period are greatly influenced by the chilling regimes used. For beef and lamb, temperature profiles that minimize cold shortening are employed that typically ensure the core temperature does not decrease below 10 °C in the first 10 hours. For pork, a more rapid chilling process is used to prevent the formation of pale, soft exudative (PSE) meat. A description of the different chilling methods is provided in chapter 5.

In red meat commercial slaughter houses, carcasses are placed in the chilling unit immediately after slaughter where they usually remain for 48-72 hours before being moved to the boning hall. Hot or warm boning is allowed under certain conditions. Although it has many advantages including; increased yield, reduced costs and less requirement for chiller space (Pisula and Tyburcy, 1996; Rees et al, 2002; Seifert et al. 2004), it is rarely used in Europe. This has been attributed to concerns regarding reduced shelf-life and the proliferation of pathogenic bacteria in subsequently vacuum packaged meat (Yang et al., 2011). The surface of boned beef cuts from conventionally chilled carcasses decreases to 8 °C or less within a few hours. In contrast, hot boned and vacuum packaged meat may have a surface temperature of up to 25 °C for several hours, supporting the proliferation of spoilage and pathogenic organisms (Sheridan and Sherington, 1982).

The duration of carcasses in the chilling units may be extended beyond 72 hours to improve the quality of the meat, a process referred to as natural conditioning or aging. This is achieved through changes in the proteins around the muscle fibres and connective tissue due to the action of natural enzymes within the meat. For beef, ageing might require up to six weeks which may take place during carcass chilling and/or when the vacuum packed primals (pieces of meat separated from the carcass during deboning) are stored under refrigerated conditions. Electrical stimulation is used primarily to avoid cold shortening in beef and lamb carcasses but also contributes to faster tenderisation. Electrical stimulation is often performed by low voltage stimulation (40V – 100V lasting for more than 30 seconds) on the slaughter line or by high voltage stimulation (often up to 1000V and even higher lasting for 30 – 90 seconds) (Nazli et al., 2010) in a separate section after the slaughter and dressing (Aalhus et al., 1994; Nazli et al., 2010; Rashid et al., 1983). Tenderisation may also be achieved by injection of salt and polyphosphates or massaging in a drum, as is used with pork (Warriss, 2010).

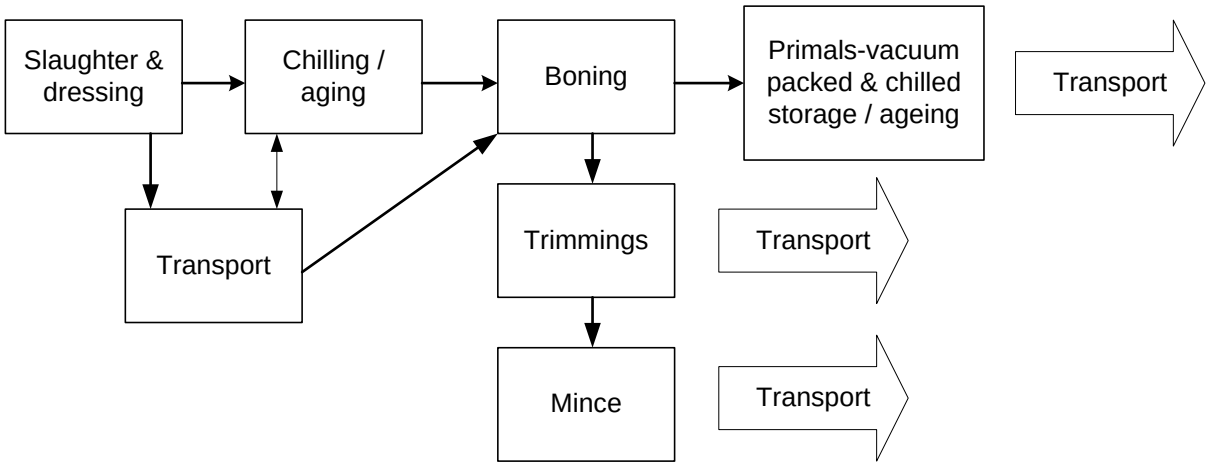

Figure 2: Summary flow diagram for conventional chilling, transportation and further processing of red meat carcasses

While the primary chillers are usually located at the end of the slaughter-line, in some instances the carcasses may be transported to other chilling units where aging takes place. If the boning hall is not attached to or located adjacent to the slaughterhouse, transportation may also take place between the chilling and boning stages. In the boning hall, which operates at a maximum temperature of 12 °C, the carcass is deboned, the different muscles are removed, cut into primals and usually vacuum packaged. This process produces trimmings that may be minced immediately but are usually stored chilled or frozen before transportation to another meat processing operation such as burger manufacture. The vacuum packaged primals are stored at temperatures of 0 to 4 °C for periods of up to 6 weeks before being transported to retail customers.

5. Review of chilling methods and effect on temperature profile

The principles of mechanical refrigeration date back to around 1750 and within 100 years commercial scale equipment was in use in the food industry. After slaughter and dressing, red meat carcasses are at the optimum temperature for the growth of pathogenic and spoilage organisms. It is therefore essential that they be chilled to temperatures that retard growth. Chilling is also critical for appearance and eating quality. Most carcasses are refrigerated using a system based on forced convection air chilling. Reducing the temperature and/or increasing the air velocity increase the chilling rate and enhances carcass drying both of which retard the growth or pathogenic and spoilage organisms (Ockerman and Basu, 2004). However, if beef and lamb carcasses are chilled too quickly cold shortening and toughening of the meat occurs. Super-chilling, is performed at -1 °C to -2 °C and in this process the water content in the food is partially frozen before ice distribution equilibrates and a uniform temperature is achieved throughout the product. This technology is almost exclusively used in the fish industry in Europe although there is increasing interest in its application for prolonged meat storage (Schubring, 2009).

5.1. Air chilling

Air chilling is commonly used in the meat and poultry industries (James and James, 2004). Immediately after slaughter and dressing, carcasses are mechanically pulled or pushed into large insulated chilling rooms on connecting rails. When the chilling room is full, the doors are closed and the carcasses are chilled for a predetermined time. Cold refrigerated air is produced by evaporator coils positioned above the chill rooms. Within each coil, a low pressure liquid evaporates using heat extracted from the surrounding medium. The gas from this evaporator coil is then compressed and the high pressure gas, often referred to as 'hot gas', is passed through another coil referred to as a 'condenser coil' where it condenses releasing heat. It then passes through an expansion valve back into the evaporator coil. In this system fans serve a dual function of pushing air over the evaporator coils and distributing the subsequently chilled air throughout the chill room. As the chilled air comes in

contact with the surface of the carcasses the meat cools and the air increases in temperature. This warmed air is then returned to the evaporator coil to be re-chilled.

5.2. Spray chilling

Spray chilling operates on the same principle as air chilling except potable water is chilled by passage between the evaporator coils before being applied to the carcasses as a fine spray. It is primarily used in the poultry industry where it is both hygienic and economical (James and James, 2004), but may also be used in beef, pork and lamb plants (Brown et al., 1993; Brown and James, 1992). Chilling using a spray system is faster than using air as applying water directly onto the carcasses improves chilling rates through evaporative cooling. It also prevents carcass shrinkage as the water applied replaces water lost through evaporation (Gigiel et al., 1989). In contrast, *post-mortem* shrinkage of up to 2% has been reported during the initial 24 h of conventional air chilling of beef, pork and lamb carcasses (Greer and Jones, 1997). This advantage may however be lost as there is some evidence of increased purge loss in spray chilled beef sides after 15 days of vacuum pack storage (Allen et al., 1987). Spray chilling systems do not operate on a continuous basis as this would require very large volumes of chilled water (estimated to be 12 l per bird in the case of poultry chilling). They rely instead on intermittent sprays typically at 5 and 15 minutes after the start of air chilling that is repeated on four or five occasions for up to 3 to 8 h post-slaughter depending on the carcass type (Hoppe et al., 1991).

5.3. Rapid chilling

Rapid chilling also referred to as 'ultra-rapid', 'fast/very fast', 'extreme' 'blast' and 'accelerated air' chilling, occurs at temperature as low as -35 °C and may be used to achieve the regulatory requirement of 7 °C or lower core temperature before moving the carcass to the boning hall. Very fast chilling may be defined as achieving a carcass temperature of -1 °C within 5h *post-mortem* (Aalhus et al., 2002).

Rapid chilling offers many advantages including a reduction in labour as well as the costs associated with materials, chilling and storage (Mallikarjunan and Mittal, 1996). It also facilitates increased product turnover while overcoming peak load, drip and evaporative loss problems. In practice it may be difficult to achieve because of the low thermal conductivity in carcasses.

There is conflicting evidence about the effect of rapid chilling on carcass quality. When used in beef, research by Joseph (1996) suggested rapid chilling resulted in considerable toughening of the meat. Similar observations have been reported with lamb (Watt and Herring, 1974) and pork (Reagan and Honikel, 1985). In contrast, Bowling et al. (1987) used rapid chilling to produce beef that was more tender and more juicy than conventionally chilled sides. Shrinkage was also reduced by 0.9% during the first 24h *post-mortem*. Sheridan (1990) reported that ultra-rapid chilling of lamb at air temperatures of -20 °C for 3-5 h with an air speed of 1.5 m/s produced tender loins after 7 days of storage.

5.4. Secondary chilling

Red meat boning halls and poultry cutting rooms typically operate at temperatures of up to 12 °C. During boning/cutting the surface temperature of the meat increases and secondary chilling is required. This secondary chilling is usually achieved using air based refrigeration systems and is often more efficient than primary chilling because the products start at a lower temperature and are much smaller than the carcasses from which they were derived.

5.5. Chilling methods as applied to beef, pork and lamb

In general, immersion chilling is the fastest method for reducing the temperature of carcasses, followed by spray (sometimes referred to as evaporative) chilling and air chilling but only air and spray chilling are used in commercial red meat plants.

Immersion chilling is not suitable for use in the red meat industry where air and to a lesser extent spray systems are applied. With beef, pork and lamb carcasses other factors, in addition to chilling method, influence the rate of temperature decline. These include size, shape, fat content, initial carcass temperature, relative humidity and airflow (Smulders et al., 1992). Spray chilling has been used in the initial stages of beef carcass refrigeration in the USA since the 1980s. Applying water to the carcasses substantially increases the rate of carcass temperature decline as compared to air chilling as the rates of heat transfer are increased due to the evaporation of the added water (James, 1996). Jones and Robertson (1988) reported that *M. semimembranosus* and *M. longissimus dorsi* in beef carcasses had consistently lower muscle temperatures (by 1-2 °C) when spray chilled as compared to conventional air chilling. This effect was most enhanced in the former, as muscles in the round are closer to the spray source. Lee et al. (1990) reported a similar observation while Jones and Robertson (1988) suggested this effect was further enhanced when the muscle had a relatively thin fat cover. Similar observations have been reported with lamb carcasses (Brown et al., 1993).

The bacterial load on carcasses may increase, decrease or remain the same as a result of air chilling (Lenahan et al., 2010). The effect of other chilling systems is similarly unclear as there are conflicting reports on the effect of air versus spray chilling on the microbial status of red meat carcasses. Greer and Dilts (1988) observed increased bacterial growth with spray systems but Hamby et al. (1987) and Kinsella et al., (2006) suggest water sprays do not affect total viable count (TVC), total *Enterobacteriaceae* count (TEC) or total coliform count (TCC).

The rate of temperature reduction directly affects the quality and palatability of red meat. Beef and lamb carcasses are usually subjected to controlled chilling where the pH, temperature and time are monitored to ensure cold shortening does not occur. Thus beef carcasses are typically chilled in air at 2 °C to 4 °C with an air velocity of less that 1 m s^{-1} and a relative humidity greater than 80% and are aged for 5-21 days. Alternatively the first 10 h chilling may be performed at higher temperatures if required to prevent cold shortening. Data provided by a commercial export beef plant was reviewed by the BIOHAZ Panel and considered representative of the chilling regimes used in the European beef industry (see Appendix B). This showed the ambient temperature in the chillers was approximately 11 °C for the first 10 hours, thereafter decreasing to approximately 1.5 °C to 3 °C. Using this regime the surface temperature decreased from 25.2 °C to 11.4 °C after 10 h; to 2.9 °C after 24h and to 1.6 °C after 36 h, thereafter remaining at that temperature. The corresponding deep round temperatures were 39.2 °C upon entering the chiller, 21.7 °C after 10 h; 8.6 °C after 24 h; 4.57 °C after 36 h and 2.9 °C after 48h. Nagy et al. (2008) reported that it took 15 to 17 h for beef carcasses (thigh muscle) to reach 7 °C at an average chill room temperature of 3.6 °C to 3.9 °C.

At an average air temperature of 1.3 °C the surface and thigh muscle temperatures of conventionally chilled lamb reached 8.8 °C and 13.8 °C after 3 hours; 4.7 °C and 7 °C after 6 h and 1.9 °C and 2.2 °C after 9 hours (data provided by commercial slaughterhouses and reviewed by the BIOHAZ Panel-see Appendix B).

In contrast, a more rapid chilling process is required for pork. To prevent the development of pale, soft, exudative (PSE) meat, internal muscle temperatures of 10 °C at 12 hours and 2-4 °C at 24 h are recommended. Nagy et al. (2008) reported that it took from 7 h and 55 min (average chill temperature of 0.6 °C) to 16 h and 13 minutes (average chill temperature of 5.5 °C) for pork (thigh muscle) to reach the same target of 7 °C. In some pork plants blast chilling is used at the start of the chilling cycle for approximately 1 h. During this process the ambient temperature can be lower than -20 °C. Under these conditions the surface temperature may reach 0 to 1 °C. However, as the air speed is reduced to normal conventional chilling rates, the ambient temperature can increase to 5 °C with a concomitant increase in the carcass surface to 10 °C or 12 °C (Nesbakken et al., 2008).

Although not generally used, very fast (-20 to -35 °C), ultra rapid (-20 °C with an air velocity of 1.5m s-1) and accelerated (-32 °C for 100 minutes) chilling have been tested with beef, lamb and pork carcasses, respectively (Ockerman and Basu, 2004). Very fast chilling improved the tenderness of beef carcasses after 6 days with a significant reduction in chill loss, a slower rate of pH decline and an

increased perception of marbling. However, the meat was darker in colour and drip loss increased. Ultra rapid chilling of lamb carcasses produced meat as tender as conventionally air chilled carcasses while rapid chilling of pork carcasses reduced drip loss without affecting tenderness.

5.6. Chilling capacity of transport vehicles

There are major differences in the quality of transport vehicles for carcasses and meat in Europe, especially in terms of cooling capacity regarding transport over short distances. However, vehicles used for long distance transport in Europe usually have a good chilling capacity. Thus it is interesting to compare the chilling effect of a chilling cell in the slaughterhouse with the chilling effect of a modern vehicle used for long distance transport. One standard vehicle with a volume of 90 m^3 is able to transport approximately 75 beef carcasses or 300 pig carcasses (about 20 – 22 tons). These vehicles are usually equipped with a refrigeration unit with a capacity of 15 kW providing airflow with about 60 changes per hour. A typical slaughterhouse chilling cell for 75 beef carcasses has a refrigeration unit with an output of approximately 50 kW providing airflow with about 200 changes per hour. Based on these data the chilling effect in a chilling cell in the slaughterhouse is about three times higher compared to the effect of chilling in a modern transport vehicle, but there is usually enough capacity to continue chilling during transport. A temperature decrease of approximately 1°C decrease (core temperature) per hour can be achieved during transportation. The chilling effect is lower in periods when the vehicle is stationary and the system runs by electricity. If the vehicle is using the internal battery the capacity is about 50 % of the capacity when the vehicle is on the road, and a core temperature decrease of the carcass will not be achieved.

The effect of chilling during transport of carcasses was investigated in a study from the early nineties (Frøystein et al., 1992). The study comprised a total of 165 transports divided into 61 shipments of sheep and lambs, 36 shipments of cattle and 68 shipments of pigs. The range of the core temperature of the carcasses before loading of the truck was 10 - 20°C. The transportation was carried out by vehicles designed for longer transportation and 13 different transport companies were represented. The carcasses were transported from nine slaughterhouses to nine facilities with cutting operations. The study showed that transport of all three animal species can be carried out in a way that ensures efficient cooling of the carcasses, with a continuous temperature decrease during transport. The main conclusion was that the core temperatures of the carcasses were 7 °C or lower 24 hours after slaughter of sheep / pigs and 48 hours after slaughter of cattle even if the core temperature was approximately 20 °C during the loading of the vehicles. This finding confirms that the chilling capacity is high in modern transport vehicles designed for long distance haulage (Appendix B). Modern transport vehicles also have equipment for continuous measurement of temperature in the front and the back of the vehicle. Accordingly the temperatures are often logged during transport and these data are used for HACCP verification.

6. Modelling

6.1. Pathogen growth

Growth of pathogens during carcass chilling and transportation was estimated based on available secondary models predicting the growth rate of *Salmonella* spp., VTEC, *L. monocytogenes* and *Y. enterocolitica*. For VTEC, the model of Ross et al. (2003) for *Escherichia coli* was used assuming a similar kinetic behaviour of this organism to VTEC. The selection of this model was based on the fact The minimum temperatures for growth was assumed to be 7.0 °C for *Salmonella* spp. and VTEC, 1.0 °C for *L. monocytogenes* and -1.0 °C for *Y. enterocolitica.* Growth of the pathogens was calculated by introducing the estimated growth rate from the secondary model to a primary model (Baranyi and Roberts, 1994), assuming no lag phase, N_0=0 log CFU/cm^2 and N_{max}=8 log CFU/cm^2. Growth rates decline with temperature and based on the chilling curves, growth rates were estimated every 10 minutes using the secondary model. The mean growth rate in each time interval was used to estimate the growth in that time interval and the total growth was the sum growth of all time intervals during chilling. The models and the assumed environmental conditions used in the growth predictions for the different pathogens are shown in Table 2. The assumption for the lag phase absence, together with the

assumed high a_w, and pH as well as no competition from other meat bacterial flora represents conditions that are favourable for the growth of the target pathogens and results in an over-estimation of growth. Moreover, since the approach used is based on the comparison of temperature scenarios this is not expected to affect the results and conclusions. The secondary models included in the ComBase modelling toolbox were used for the rest of the pathogens.

Table 2: Models predicting the growth rate (secondary models) and the assumed environmental conditions used in the growth predictions

Model	Source[a]	Model type	Temperature Range[b] (°C)	pH (meat)	a_w (meat)	Total lactic acid mM[c]
Salmonella spp.	ComBase	Polynomial	7.0-40.0	6.5	0.993	Not included
Escherichia coli	Ross et al., 2003	Square root	7.63-47.43	6.5	0.993	51.7
Listeria monocytogenes	ComBase	Polynomial	1.0-40.0	6.5	0.993	51.7
Yersinia enterocolitica	ComBase	Polynomial	-1.0-37.0	6.5	0.993	Not included

a: see details in Appendix C
b: Temperature range used for the development of the model
c: Naturally occurring

6.2. Development of baseline scenarios

In order to model the growth of *Salmonella* spp., *E. coli* (VTEC), *L. monocytogenes* and *Y. enterocolitica*, a surface temperature-time baseline scenario that represents the current situation had to be developed for each meat species. Based on the requirements in the current legislation, each baseline scenario consisted of two stages; chilling in the slaughterhouse and chilling during transport. The baseline scenarios were taken to represent a situation where carcasses remain in the chilling room until the core temperature reaches 7°C and are then transported at a constant surface temperature for 48 hours. The mean baseline is the calculated mean surface temperature profile during chilling in the slaughterhouse to a core temperature of 7°C and transportation at a constant surface temperature of 4°C for 48 hours. The worst case scenario baseline is the calculated "worst case surface temperature profile" (see Appendix A) during chilling in the slaughterhouse to a core temperature of 7°C and transportation at a surface temperature of 7°C for 48 hours. The 'worst case scenario' baseline was developed based on worst case surface temperature profiles, i.e. a subset of temperature profiles that would support most bacterial growth (see Appendix A).

6.2.1. General description

Data on carcass surface temperatures during chilling was limited and the approaches taken to develop the baseline scenarios were slightly different for the different species due to the type and amount of input data that was available. In general, data on the distribution (or mean, minimum and maximum) of initial surface temperatures, chilling times and final temperatures were extracted from scientific articles and fitted to probability distributions using the @Risk Best fit function, version 6.1.2 (Palisade Corporation, 2013). The distribution with best fit to the time temperature data was selected based on the root mean squared error. Based on the resulting distributions of surface temperatures and times , surface temperatures at different times were simulated for each animal species to obtain data representing surface temperature change during chilling.

For beef and lamb, data or subsets of the simulated data were used for fitting an exponential decay equation to obtain mean and worst-case scenarios of current chilling in terms of surface temperatures.

$$T=T_0*e^{-k*t}$$

Where T=surface temperature, T_0= surface temperature at time 0, i.e. when chilling starts, and t=time.

For pork data from 42 French slaughterhouses were fitted to a modified exponential decay function (Anses, 2014):

$$T = T_a + (T_0 - T_a) * e^{-k*t}$$

Where T_a is the asymptotic final temperature and the other parameters are as described above.

The models were fitted to the data using the nonlinear least squares (nls) method for non-linear curve fitting included in the R statistical and modelling software (R Core Team, 2013). The time it takes to reach a core temperature of 7 °C was estimated based on the scientific literature and available observations from slaughterhouses. During transport the baseline surface temperatures were assumed to be 7 or 4 °C during the whole of transportation. These temperatures are compliant with the legislation regarding transport of red meat and were taken to represent worst case and mean temperature scenarios.

A description of the data and limitations involved in developing baseline scenarios, and a summary of the specific baseline-scenarios are provided below. A detailed description of the development, i.e. input data, fitted distributions, simulated data and curve fitting, can be found in Appendix A.

6.2.2. Description of data/limitations

Current legislation is based on core temperatures and very few data are available on carcass surface temperature decline during chilling. In addition, a number of different chilling curves are compliant with the current legislation making the selection of baseline curves to some extent arbitrary. Comparing a new scenario with a baseline reflecting a slow chilling process during which much growth may occur will be less conservative than using a rapid chilling curve, with less growth, as the baseline scenario.

To develop chilling curves representing chilling in the slaughterhouse, data on the chilling of beef and lamb in Canadian slaughterhouses was used. For beef chilling, data from Gill and Landers (2003) was used representing the results of chilling 25 carcasses from each of four different plants. Additional data used was from Jericho et al. (1998), representing chilling of a total of 56 beef carcasses in two different chillers. For lamb chilling, data from Gill and Jones (1997) was used representing results of chilling 25 carcasses from one plant. The issue of how well Canadian data represent the current situation in different EU member states introduces uncertainty into the assessment. However, Canadian legislation stipulates immediate and continuous cooling of the carcass until it reaches a surface temperature of 7 °C or less within 24 hours of the end of carcass dressing (Canadian Food Inspection Agency, 2013). In addition, to evaluate the realism of the chilling curves developed based on these data, baseline scenarios were compared with individual observed carcass surface temperature data from the meat industry in Europe, specifically Ireland and Norway (Appendix B), the Netherlands (TNO, 2013) and France (Anses, 2014). For beef and lamb, both comparisons of observed chilling curves with developed baseline chilling curves and estimated *E. coli* growth based on the baseline curves suggested that the selected scenarios were realistic (Appendix A Figure 1). For instance, estimated *E. coli* growth on a beef carcass based on data in the Dutch study (TNO, 2013) was 1.68 log CFU/cm^2. This is intermediate between growth estimated in our mean (0.95 log CFU/cm^2) and worst case (2.34 log CFU/cm^2) baseline chilling curves, respectively. Thus, it was concluded that, for the purpose of the assessment, the chilling curves in the baseline scenarios were appropriate for use. For pork, data was available on carcass surface temperatures representing 42 carcasses from five French slaughterhouses (Anses, 2014). These data were used to develop a mean and worst-case pork chilling baseline. The issues of uncertainty in the data were addressed by framing the range of baselines using mean and worst-case baseline scenarios.

In the new scenarios, loading carcasses from the slaughterhouse before the core temperature is below 7 °C, the capacity of chilling during transport is crucial for the safety of the whole process. Data describing chilling rates during transport were not available. A report from 1992 indicated that, at least

in Norway, it was possible to perform adequate chilling during transport (Frøystein et al., 1992). Since the rate of chilling during transport could not be estimated, the baseline scenarios assumed constant temperatures and times of transport. As was done for the slaughterhouse stage, uncertainty was addressed by assuming a mean and a worst-case surface temperature of 4 and 7 °C, respectively. The chilling capacity during transport is an important knowledge gap and may vary widely between producers as well as between MS.

For modelling of surface temperature chilling curves in the baselines it was decided to use a constant initial surface temperature, T_0, which was estimated by fitting the model to all the data. This decision was based on observations of results from trials where values were fixed at only the higher observed initial temperatures. These trials resulted in estimated higher chilling rates than would have been achieved if using all data. This would therefore result in more rapid chilling curves and a less conservative baseline scenario. Another alternative was also evaluated, i.e. using the higher initial observed temperatures together with the chilling rates, k, estimated based on all the data. However, this would also result in more estimated growth during baseline chilling and thus, also to a less conservative baseline scenario. In addition, uncertainties introduced by the data gaps presented above were also addressed by using conservative assumptions for growth estimations, i.e. no lag-phase, and favourable pH and a_w and by not considering potential inactivation due to drying.

6.2.3. Summary of baseline scenarios

The resulting baseline scenarios consisted of two stages; chilling in the slaughterhouse and chilling during transport. Two baseline scenarios were evaluated; a mean (average) scenario and a worst-case baseline scenario, respectively. Comparisons of growth during new alternative scenarios would likely over-estimate growth as favourable conditions of pH and a_w for bacterial growth were assumed and without an initial lag period or competition from other microflora. The equations describing the carcass surface temperature over time in the slaughterhouse, the time it takes to reach a core temperature of 7 °C, and the carcass surface temperature during the 48 hour transport for the two baseline scenarios are shown in table 3.

Table 3: Summary of the baseline scenarios for beef, lamb and pork in terms of the equations describing surface temperature decline with time, and the time to reach a core temperature of 7 °C (time in slaughterhouse) and the temperature during the 48 hour transport.

	Mean baseline scenario			**Worst case baseline scenario**		
Species	Surface Temperature during chilling (°C)	Time to core temperature of 7 °C during chilling in slaughterhouse (hours)	Surface temperature during 48 hour transport	Surface Temperature during chilling (°C)	Time to core temperature of 7 °C during chilling in slaughterhouse (hours)	Surface temperature during 48 hour transport
Beef	$26.3*e^{-0.173*t}$	26.6	4	$25.8*e^{-0.069*t}$	27.3	7
Lamb	ND	ND	ND	$26.2*e^{-0.091*t}$	21.5	7
Pig	$4.2 + (12.1-4.2)*e^{-0.105*t}$	19.3	4	$6.2 + (18.3-6.2)*e^{-0.105*t}$	27.5	7

ND: not defined

6.3. Development of alternative scenarios

Growth is estimated for situations where carcasses are removed from the chilling room before a core temperature of 7 °C is reached and transported at various constant surface temperatures (between 5-10 °C) for different transportation times. The alternative scenarios evaluated are different combinations of surface temperatures achieved at the end of slaughterhouse chilling and transportation

surface temperatures. A temperature range from 5 °C to 10 °C for both the surface temperature at the end of chilling and during transportation describe a set of realistic scenarios.

6.4. Results for answering TOR 1

As microbial contamination occurs predominantly on the surface of the carcass, the surface temperature and not the core temperature will influence bacterial growth. Figures 3-8 show the predicted growth of the selected pathogens on pork and beef during chilling together with representative profiles of surface and core temperatures. Early removal for transport loading of the carcass at any core temperature above the limit of 7 °C , i.e. at times before the core temperature (green line) is below 7 °C (in figures 3-8), will in all cases result in less growth (red line in figures 3-8) during chilling in the slaughterhouse compared to the scenario where the carcasses are chilled to a core temperature of 7 °C . This bacterial growth differential, at the very least, introduces the possibility that carcasses could be removed from the slaughterhouse chiller before the core temperature of 7 °C is reached and transported without obtaining bacterial growth in excess of that which would have been obtained if the carcasses were left in the slaughterhouse chillers until 7 °C core was achieved.

Total bacterial growth is time-temperature depended. By reducing the time or temperature less growth is obtained. Removing the carcasses before the core temperature of 7 °C is reached reduces the time component. Carcass loading and transportation under proper chilled conditions (at least as effective as the slaughterhouse chiller) will maintain the temperature component. Thus, if transport temperature and time is controlled so that the total bacterial growth on the carcass is less or equivalent to that achieved with the baseline scenario based on Regulation (EC) 853/2004, it is possible to apply alternative chilling regimes.

For example, for a beef carcass remaining in the chilling room for 30 hours to reach a core temperature of 7 °C, the estimated growth of *E. coli* during this period is 1.50 log CFU/cm^2 (Figure 3). In the case where the chilling period is reduced to 18 hours (to a core temperature of 15 °C) the estimated growth is 1.45 log CFU/cm^2. In this example, the potential growth during transport cannot be greater than 0.05 (1.50 – 1.45) log CFU /cm^2 to be equivalent to growth achieved with the baseline scenario based on Regulation (EC) 853/2004. Similarly, for a beef carcass remaining in the chilling room until the core temperature reaches 7 °C (30h), the estimated growth of *L. monocytogenes* is 1.9 log CFU/cm^2 (Figure 5). To reach 15 °C (18h) the estimated growth is 1.7 log CFU/cm^2. In this example, the maximum growth during transport can be 0.2 log CFU/cm^2 to be equivalent to estimated growth during chilling in the slaughterhouse according to current legislation.

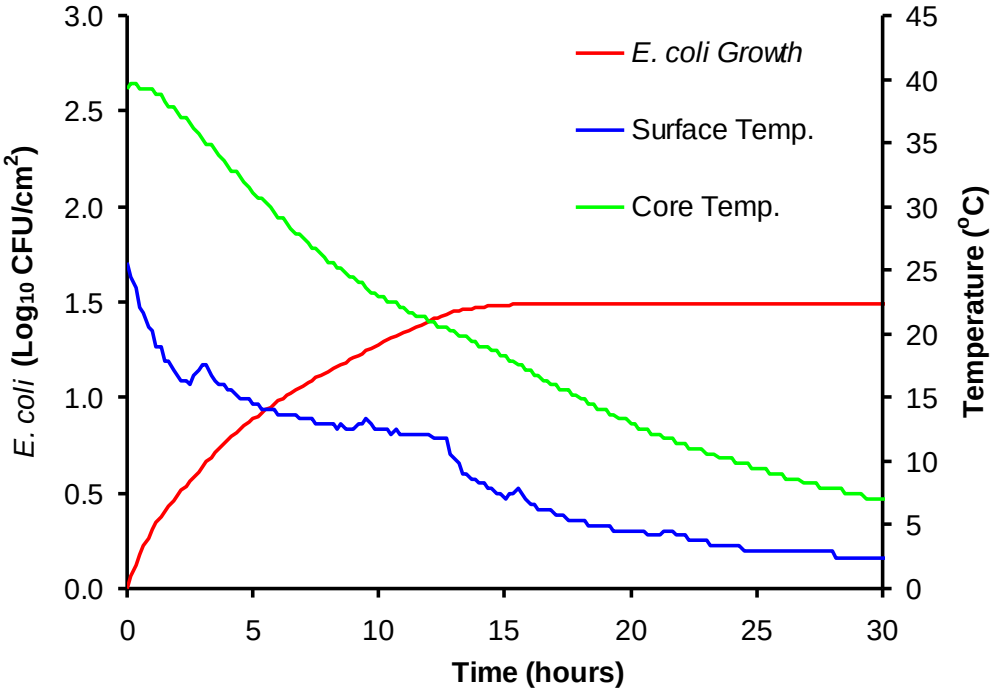

Figure 3: Predicted growth of *E. coli* (VTEC) on beef carcasses kept in the chilling room until core temperature reaches 7 °C (commercial beef slaughterhouse data). Growth of *E. coli* was predicted using the secondary model of Ross et al., 2003 (assuming pH=6.5, a_w=0.993 and lactic acid concentration=51.7mM) and the primary model of Baranyi and Roberts (1994) assuming no lag phase.

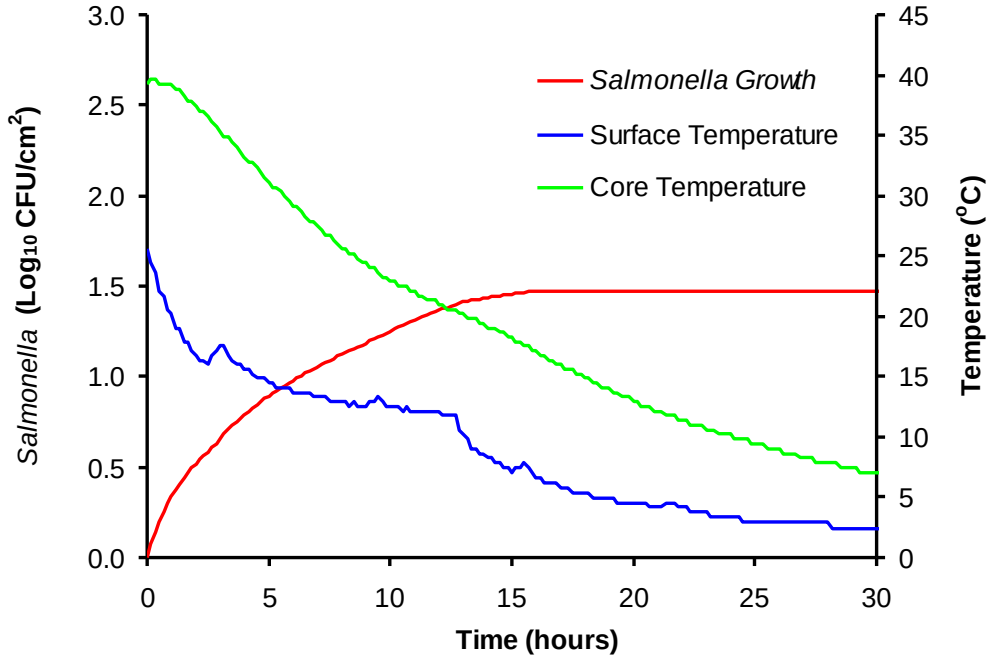

Figure 4: Predicted growth of *Salmonella* spp. on beef carcasses kept in the chilling room until core temperature reaches 7 °C (commercial beef slaughterhouse data). Growth of *Salmonella* spp. was predicted using Combase secondary model (assuming pH=6.5, a_w=0.993) and the primary model of Baranyi and Roberts (1994) assuming no lag phase.

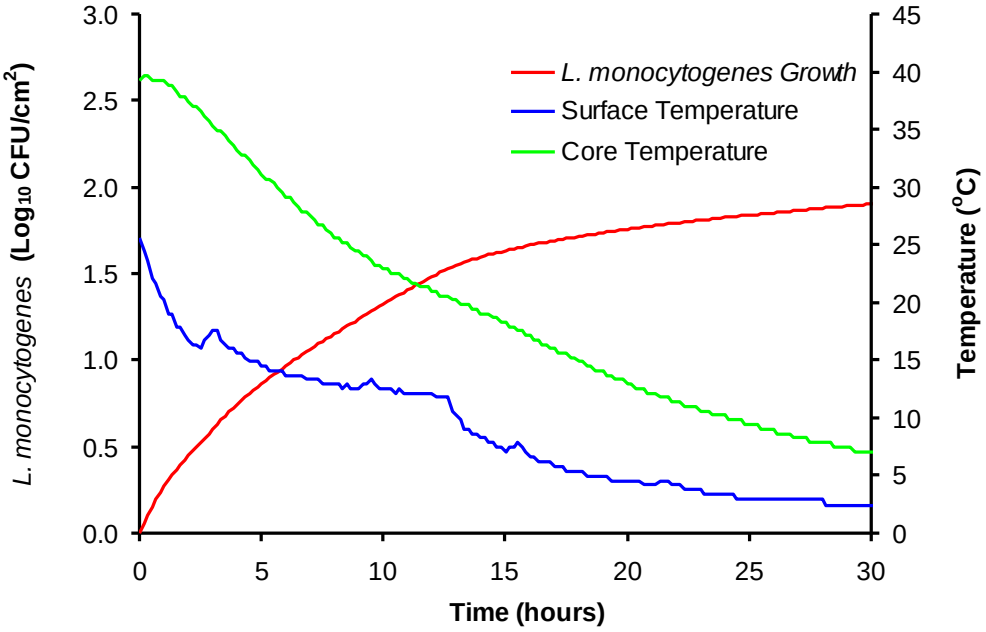

Figure 5: Predicted growth of *L. monocytogenes* on beef carcasses kept in the chilling room until core temperature reaches 7 °C (commercial beef slaughterhouse data). Growth of *L. monocytogenes* was predicted using Combase secondary model (assuming pH=6.5, a_w=0.993) and the primary model of Baranyi and Roberts (1994) assuming no lag phase.

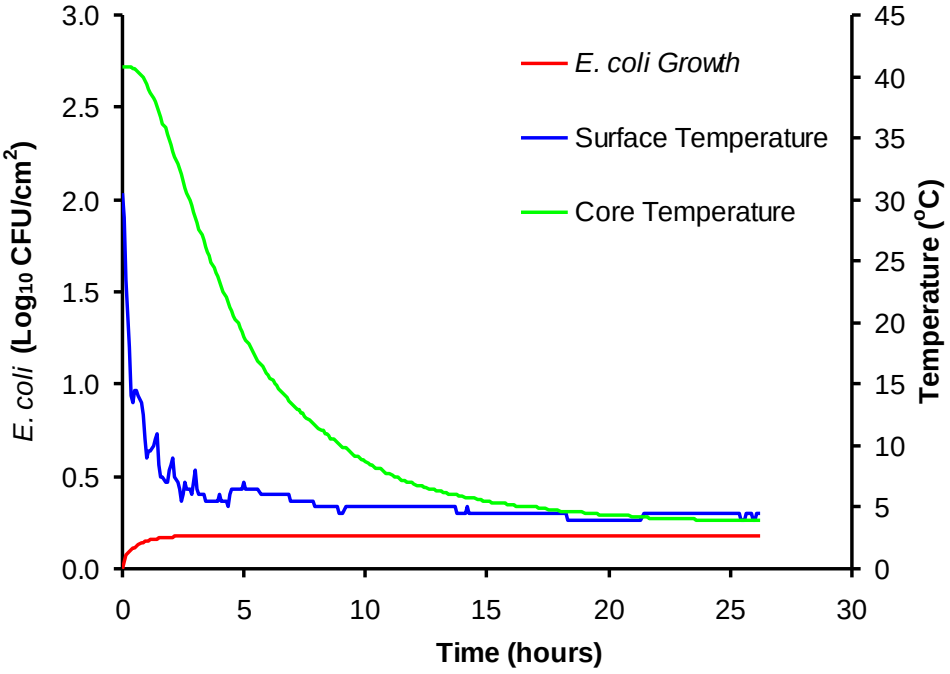

Figure 6: Predicted growth of *E. coli* (VTEC) on pork carcasses kept in the chilling room until core temperature reaches 7 °C. Growth of *E. coli* was predicted using the secondary model of Ross et al., 2003 (assuming pH=6.5, a_w=0.993 and lactic acid concentration=51.7mM) and the primary model of Baranyi and Roberts (1994) assuming no lag phase

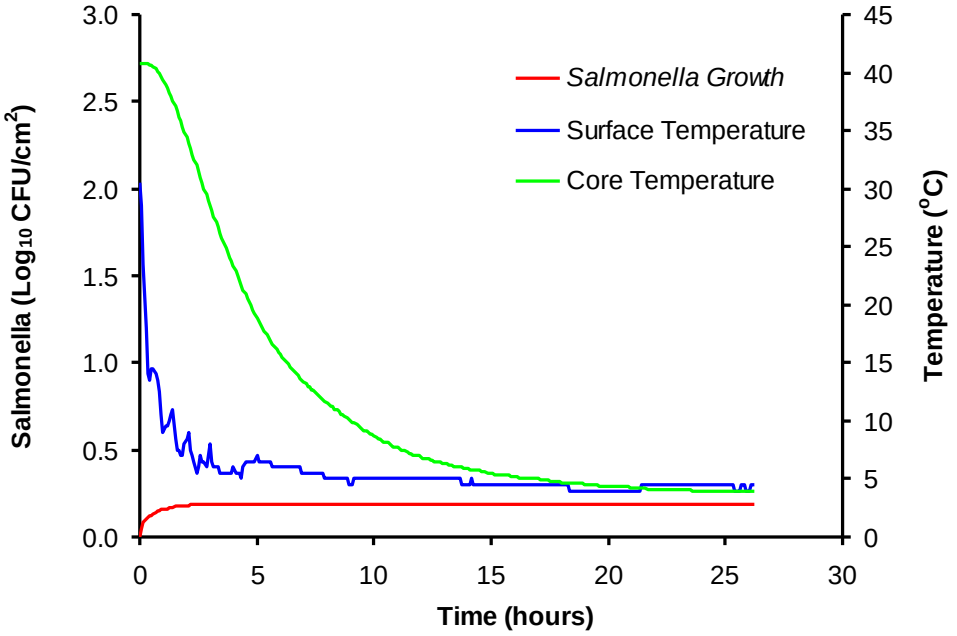

Figure 7: Predicted growth of *Salmonella* spp. on pork carcasses kept in the chilling room until core temperature reaches 7 °C. Growth of *Salmonella* spp. was predicted using the Combase secondary model (assuming pH=6.5, a_w=0.993 and lactic acid concentration=51.7mM) and the primary model of Baranyi and Roberts (1994) assuming no lag phase.

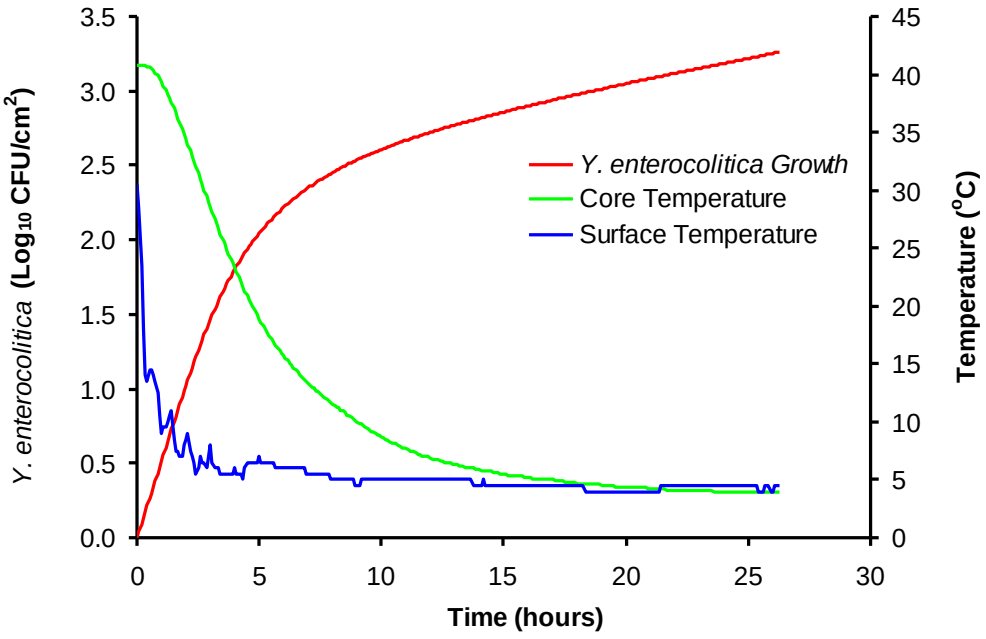

Figure 8: Predicted growth of *Y. enterocolitica* on pork carcasses kept in the chilling room until core temperature reaches 7 °C. Growth of *Y. enterocolitica* was predicted using the Combase secondary model (assuming pH=6.5, a_w=0.993 and lactic acid concentration=51.7mM) and the primary model of Baranyi and Roberts (1994) assuming no lag phase.

6.4.1. Concluding remarks TOR 1

As microbial contamination occurs at the surface of the carcass, the surface temperature was used to assess the bacterial growth potential.

It is possible to apply alternative carcass chilling regimes in the slaughter plant and during transportation, other than those required to achieve a target core temperature of 7 °C in the slaughter plant before transportation, without increasing the microbial growth of potentially harmful organisms. This is possible because bacterial growth, and associated potential risk, is related not only to the chilling time and temperature operated in the slaughterhouse but also to the chilling time and temperatures during transport and storage. It is therefore possible to control transport temperature and time to have equivalent or less growth to that obtained with the baseline scenario based on Regulation (EC) 853/2004. If at this stage there is no additional growth, the final consumer exposure will not be affected and accordingly the risk will remain equivalent to the practices described in the current regulation.

6.5. Results for answering TOR 2

The growth of the selected pathogens at various alternative scenarios defined by different combinations of chilling and transportation duration and temperatures was assessed and compared to two baseline scenarios (mean and worst case) for each animal species. For comparison, growth was expressed as Log_{10} CFU/cm^2.

6.5.1. Growth of pathogens during carcass chilling in the slaughterhouse

The predicted growth-expressed as the difference between the final concentration and a starting point equal to 1 CFU/cm^2 of selected pathogens during beef carcass chilling using the mean and the worst case temperature chilling profiles is presented in Tables 4 and 5. The growth during the time required for the carcass core temperature to reach 7 °C (current regulation) ranged from 0.95 to 3.03 log CFU/cm^2 for the different pathogens. In general, the growth of *L. monocytogenes* and *Y. enterocolitica* was higher as compared to *Salmonella* spp. and *E. coli* (VTEC) due to their ability to grow at low temperatures. The predicted growth for the worst case temperature profile was almost double compared to the mean baseline scenario.

The current regulation referring to a core temperature target of 7 °C before the carcasses leave the chilling room was compared to alternative targets for surface temperature ranging from 5 to 10 °C. The results showed that the growth of the pathogens for the alternative surface temperature targets was always equal to or lower than that predicted when the beef carcasses were chilled to a core temperature of 7 °C. As above, this was due to reducing the time component. A similar outcome was obtained with pork (Tables 6 and 7) and lamb (Table 8) carcasses.

6.5.1.1. Results for beef carcasses

Table 4: Predicted growth (log_{10} CFU/cm^2) for selected pathogens during beef carcass chilling based on the calculated mean temperature chilling profile. The time required for the carcass core temperature to reach 7 °C (current regulation) is compared to the time required for the surface to reach temperatures from 5 to 10 °C.

		Growth (Log_{10} CFU/cm^2)			
Chilling temperature limit		***Salmonella* spp.**	***E .coli* (VTEC)**	***L. monocytogenes***	***Y. enterocolitica***
Bacterial growth on the carcass when chilled to a core temperature of 7 °C (26.6 hours)		1.00	0.95	1.14	1.57
Surface T (°C)	Time in chiller (hours)				
5	9.7	1.00	0.95	1.02	1.17
6	8.5	1.00	0.95	1.00	1.13
7	7.7	1.00	0.95	0.98	1.09
8	6.8	0.98	0.94	0.95	1.04
9	6.2	0.97	0.93	0.93	1.01
10	5.6	0.95	0.91	0.89	0.96

Table 5: Predicted growth (log_{10} CFU/cm^2) for selected pathogens during beef carcass chilling based on the calculated worst case temperature chilling profile. The time required for the carcass core temperature to reach 7 °C (current regulation) is compared to the time required for the surface to reach temperatures from 5 to 10 °C.

		Growth (Log_{10} CFU/cm^2)			
Chilling temperature limit		***Salmonella* spp.**	***E. coli* (VTEC)**	***L. monocytogenes***	***Y. enterocolitica***
Bacterial growth on the carcass when chilled to a core temperature of 7 °C (27.3 hours)		2.44	2.32	2.59	3.03
Surface T (°C)	Time in chiller (hours)				
5	24.9	2.44	2.32	2.53	2.90
6	21.2	2.44	2.32	2.47	2.80
7	19.0	2.44	2.32	2.41	2.69
8	17.0	2.41	2.31	2.34	2.58
9	15.2	2.37	2.28	2.27	2.47
10	13.8	2.33	2.24	2.19	2.36

Tables 6-8 present the predicted growth of the selected pathogens for pork and lamb carcasses. As expected, the rate of temperature decrease for these species was faster compared to beef carcasses due to their smaller size. As a result the predicted growth of the selected pathogens was in general lower. The trends however, for both species were similar to beef carcasses.

6.5.1.2. Results for pork carcasses

Table 6: Predicted growth (log_{10} CFU/cm^2) for selected pathogens during pork carcass chilling based on the calculated mean temperature chilling profile. The time required for the carcass core temperature to reach 7 °C (current regulation) is compared to the time required for the surface to reach temperatures from 5 to 10 °C.

		Growth (Log_{10} CFU/cm^2)			
Chilling temperature limit		***Salmonella* spp.**	***E .coli* (VTEC)**	***L. monocytogenes***	***Y. enterocolitica***
Bacterial growth on the carcass when chilled to a core temperature of 7 °C (19.3 hours)		0.28	0.24	0.71	1.11
Surface T (°C)	Time in chiller (hours)				
5	21.2	0.28	0.24	0.71	1.11
6	14.2	0.28	0.24	0.59	0.90
7	9.8	0.28	0.24	0.47	0.69
8	8.0	0.23	0.21	0.37	0.53
9	4.8	0.18	0.17	0.28	0.39
10	3.0	0.13	0.13	0.19	0.26

Table 7: Predicted growth (log_{10} CFU/cm^2) for selected pathogens during pork carcass chilling based on the calculated worst case temperature chilling profile. The time required for the carcass core temperature to reach 7 °C (current regulation) is compared to the time required for the surface to reach temperatures from 5 to10 °C.

		Growth (Log_{10} CFU/cm^2)			
Chilling temperature limit		***Salmonella* spp.**	***E .coli* (VTEC)**	***L. monocytogenes***	***Y. enterocolitica***
Bacterial growth on the carcass when chilled to a core temperature of 7 °C (27.5 hours)		1.19	1.17	1.70	2.29
Surface T (°C)	Time in chiller (hours)				
5	>27.5	1.19	1.15	1.70	2.29
6	>27.5	1.19	1.15	1.70	2.29
7	26.2	1.18	1.15	1.66	2.22
8	18.0	1.05	1.07	1.39	1.79
9	14.0	0.96	1.00	1.21	1.52
10	11.0	0.87	0.92	1.06	1.30

6.5.1.3. Results for lamb carcasses

Table 8: Predicted growth (log_{10} CFU/cm^2) for selected pathogens during lamb carcass chilling based on the calculated worst case temperature chilling profile. The time required for the carcass core temperature to reach 7 °C (current regulation) is compared to the time required for the surface to reach temperatures from 5 to 10 °C.

		Growth (Log_{10} CFU/cm^2)			
Chilling temperature limit		***Salmonella* spp.**	***E .coli* (VTEC)**	***L. monocytogenes***	***Y. enterocolitica***
Bacterial growth on the carcass when chilled to a core temperature of 7 °C (21.5 hours)		1.93	1.84	2.03	2.36
Surface T (°C)	Time in chiller (hours)				
5	18.2	1.93	1.83	1.97	2.25
6	16.2	1.93	1.83	1.92	2.17
7	14.5	1.92	1.82	1.88	2.09
8	13.0	1.90	1.81	1.82	2.00
9	11.8	1.87	1.79	1.77	1.93
10	10.5	1.84	1.76	1.73	1.85

6.5.2. Growth of pathogens during transportation

The predicted growth of selected pathogens during carcass transportation with various surface temperatures and for various transportation times is presented in Tables 9 (*Salmonella* spp.), 10 (*E. coli* (VTEC)), 11 (*L. monocytogenes*) and 12 (*Y. enterocolitica*). For *Salmonella* spp. and VTEC, the predicted growth at 10 °C after 48 hours was 1.61 and 1.54 log cfu/cm^2, respectively. The predicted growth of *L. monocytogenes* using the same time-temperature combination was 2.61 log cfu/cm^2.

Table 9: Predicted growth of *Salmonella* spp. during carcass transportation with various surface temperature and times.

	***Salmonella* spp.**					
Time (h)	**Surface temperature (°C)**					
	5	**6**	**7**	**8**	**9**	**10**
	Log_{10} CFU/cm^2					
1	0.00	0.00	0.00	0.02	0.03	0.03
2	0.00	0.00	0.02	0.04	0.05	0.07
3	0.00	0.00	0.03	0.06	0.08	0.10
6	0.00	0.00	0.08	0.12	0.16	0.20
12	0.00	0.00	0.17	0.24	0.31	0.40
24	0.00	0.00	0.36	0.49	0.63	0.81
48	0.00	0.00	0.73	0.97	1.26	1.61

Table 10: Predicted growth of *E. coli (*VTEC) during carcass transportation with various surface temperatures and times.

E. coli (VTEC)						
Time (h)	**Surface temperature (°C)**					
	5	**6**	**7**	**8**	**9**	**10**
	Log_{10} CFU/cm^2					
1	0.00	0.00	0.01	0.01	0.02	0.03
2	0.00	0.00	0.02	0.03	0.04	0.06
3	0.00	0.00	0.02	0.04	0.07	0.10
6	0.00	0.00	0.05	0.08	0.13	0.19
12	0.00	0.00	0.09	0.17	0.27	0.39
24	0.00	0.00	0.18	0.34	0.53	0.77
48	0.00	0.00	0.37	0.67	1.06	1.54

Table 11: Predicted growth of *L. monocytogenes* during carcass transportation with various surface temperature and times.

L. monocytogenes						
Time (h)	**Surface temperature (°C)**					
	5	**6**	**7**	**8**	**9**	**10**
	Log_{10} CFU/cm^2					
1	0.02	0.03	0.03	0.04	0.05	0.05
2	0.04	0.05	0.06	0.08	0.09	0.11
3	0.06	0.08	0.09	0.11	0.14	0.16
6	0.13	0.15	0.19	0.23	0.27	0.33
12	0.25	0.31	0.38	0.46	0.55	0.65
24	0.51	0.62	0.75	0.91	1.09	1.31
48	1.01	1.24	1.51	1.82	2.19	2.61

Table 12: Predicted growth of *Y. enterocolitica* during carcass transportation with various surface temperature and times.

Y. enterocolitica						
Time (h)	**Surface temperature (°C)**					
	5	**6**	**7**	**8**	**9**	**10**
	Log_{10} CFU/cm^2					
1	0.04	0.04	0.05	0.06	0.07	0.08
2	0.08	0.09	0.10	0.12	0.14	0.16
3	0.12	0.13	0.16	0.18	0.20	0.23
6	0.23	0.27	0.31	0.36	0.41	0.47
12	0.46	0.54	0.62	0.71	0.82	0.93
24	0.93	1.08	1.24	1.43	1.64	1.86
48	1.86	2.16	2.49	2.86	3.27	3.73

6.5.3. Comparison between baselines and alternatives scenarios

In order to assess if it is possible to apply alternative carcass chilling regimes, other than those mandated by current legislation Reg. (EC) 853/2004 without incurring additional bacterial growth and increasing the potential public health risk, a comparison between the baseline temperature scenarios representing the current situation and alternative temperature scenarios was performed. In particular the following scenarios were tested.

Baseline scenarios

- **Mean**: Chilling of carcass at the mean estimated chilling temperature profile until the core temperature reaches 7 °C and subsequent transportation with a surface temperature of 4 °C.

- **Worst case**: Chilling of carcass at the worst estimated chilling temperature profile until the core temperature reaches 7 °C and subsequent transportation with a surface temperature of 7 °C.

Alternative scenarios

- Chilling of carcass until the surface temperature reaches temperatures from 5 to 10 °C and subsequent transportation with a surface temperature of 5 to 10 °C.

The comparison allowed the estimation of transportation time for alternative chilling scenarios required to achieve an equivalent growth of the relevant pathogens as compared to the mean and worst baseline scenarios for beef carcasses. Only the alternative scenarios with 1 °C difference between the carcass surface temperature at the end of chilling and the ambient transportation temperature were evaluated assuming an instantaneous adjustment of carcass surface temperature to the ambient transportation temperature. The latter was applied because there no temperature rate data available for the temperature equilibrium during transportation.

The transportation times for alternative chilling scenarios required to achieve an equivalent growth of *Salmonella* spp. as compared to the mean and worst baseline scenario are presented for beef, pork and lamb carcasses in Tables 13, 14 and 15, respectively. The transportation times for equivalent growth of *E. coli* (for VTEC), *L. monocytogenes* and *Y. enterocolitica* can be found in Appendix D.

To illustrate the alternative scenarios and how these tables may be used to predict transport time-temperature combinations that may be used with a specific carcass surface temperature (achieved in the slaughterhouse chiller) that give equivalent pathogen growth as compared to the baseline scenarios, an alternative scenario was selected in which a beef carcass is removed from the chilling room when its surface temperature is 5 °C and transported with ambient temperature of 6 °C, from Table 13, the transportation time that would give an equivalent amount of growth for *L. monocytogenes* to that which would be obtained with the mean baseline scenario (chilling to a core temperature of 7 °C and transportation at 4 °C for 48 hours) is 36.4 hours. For the same alternative scenario the transportation time that would give an equivalent amount of growth for *L. monocytogenes* as compared to the worst baseline scenario (chilling to a core temperature of 7 °C and transportation at 7 °C for 48 hours) increases to 60.7 hours (also Table 13).

By combining the results for all tested pathogens it is possible to identify alternative carcass chilling and transportation regimes, other than those mandated by current legislation (Reg. (EC) 853/2004) without incurring additional bacterial growth and increasing the potential public health risk. Combinations of surface temperature of beef and pork carcasses at the end of chilling process and maximum transportation time at various temperatures required to achieve less or equivalent growth of all tested pathogens as compared to the mean and worst baseline scenario are presented in Tables 16-18 for beef and in Appendix D for pork.

6.5.3.1. Equivalent growth of *Salmonella* spp. in beef

Table 13: Transportation time required to achieve an equivalent growth of *Salmonella* spp. as compared to the mean and worst case baseline scenario for beef carcasses

Target surface temperature achieved during carcass chilling	Surface temperature during transportation					
	5 °C	6 °C	7 °C	8 °C	9 °C	10 °C
	Growth rate (log cfu/cm2/h)					
	0.000	0.000	0.015	0.020	0.026	0.034
	Transportation time (hours) required for the equivalent growth of *Salmonella* spp. to mean baseline scenario:					
5 °C	ng	ng				
6 °C	ng	ng	0.0			
7 °C		ng	0.0	0.0		
8 °C			1.3	1.0	0.8	
9 °C				1.5	1.1	0.9
10 °C					1.9	1.5
	Transportation time (hours) required for the equivalent growth of *Salmonella* spp. to worst baseline scenario					
5 °C	ng	ng				
6 °C	ng	ng	48.7			
7 °C		ng	48.7	36.1		
8 °C			50.7	37.5	29.0	
9 °C				39.5	30.5	23.8
10 °C					32.0	25.0

ng: no growth at this transportation temperature

6.5.3.2. Equivalent growth of *Salmonella* spp. in pork

Table 14: Transportation time required to achieve an equivalent growth of *Salmonella* spp. as compared to the mean and worst case baseline scenario for pork carcasses

Target surface temperature achieved during carcass chilling	Surface temperature during transportation					
	5 °C	6 °C	7 °C	8 °C	9 °C	10 °C
	Growth rate (log cfu/cm2/h)					
	0	0	0.015	0.020	0.026	0.034
	Transportation time (hours) required for the equivalent growth of *Salmonella* spp. to mean baseline scenario:					
5 °C	ng	ng				
6 °C	ng	ng	0.0			
7 °C		ng	0.0	0.0		
8 °C			1.3	1.0	0.8	
9 °C				1.5	1.1	0.9
10 °C					1.9	1.5
	Transportation time (hours) required for the equivalent growth of *Salmonella* spp. to worst baseline scenario					
5 °C						
6 °C						
7 °C		ng	48.7	36.1		
8 °C			50.7	37.5	29.0	
9 °C				39.5	30.5	23.8
10 °C					32.0	25.0

ng: no growth at this transportation temperature

6.5.3.3. Equivalent growth of *Salmonella* spp. in lamb

Table 15: Transportation time required to achieve an equivalent growth of *Salmonella* spp. as compared to the worst case baseline scenario for lamb carcasses

Target surface temperature achieved during carcass chilling	Surface temperature during transportation					
	5 °C	6 °C	7 °C	8 °C	9 °C	10 °C
	Growth rate (log cfu/cm2/h)					
	0	0	0.015	0.020	0.026	0.034
	Transportation time (hours) required for the equivalent growth of *Salmonella* spp. to worst baseline scenario:					
5 °C	ng	ng				
6 °C	ng	ng	48.7			
7 °C		ng	49.3	36.6		
8 °C			50.7	37.5	29.0	
9 °C				39.0	30.1	23.5
10 °C					31.3	24.4

ng: no growth at this transportation temperature

6.5.3.4. Combined results for all tested pathogens for beef

The combined results for all tested pathogens for pork are presented in Appendix D.

Table 16: Combinations of surface temperature of beef carcasses at the end of chilling process and maximum transportation time at 5 °C that achieve less or equivalent growth of all tested pathogens as compared to the mean and worst case baseline scenario.

	Carcass surface temperature at the end of chilling (°C)	Maximum transportation time (hours)
Mean baseline scenario	4	43.2
	5	44.6
	6	45.6
Worst case baseline scenario	4	71.6
	5	74.4
	6	77.3

Table 17: Combinations of surface temperature of beef carcasses at the end of chilling process and maximum transportation time at 6 °C that achieve less or equivalent growth of all tested pathogens as compared to the mean and worst case baseline scenario.

	Carcass surface temperature at the end of chilling (°C)	Maximum transportation time (hours)
Mean baseline scenario	5	36.4
	6	37.2
	7	38.0
Worst case baseline scenario	5	60.7
	6	63.1
	7	65.4

Table 18: Combinations of surface temperature of beef carcasses at the end of chilling process and maximum transportation time at 7 °C that achieve less or equivalent growth of all tested pathogens as compared to the mean and worst case baseline scenario.

	Carcass surface temperature at the end of chilling (°C)	Maximum transportation time (hours)
Mean baseline scenario	6	0.0
	7	0.0
	8	1.3
Worst case baseline scenario	6	48.0
	7	48.0
	8	49.3

6.5.4. Concluding remarks TOR 2

Predictive models for the growth of *Salmonella* spp., VTEC, *L. monocytogenes* and *Y. enterocolitica* in beef, pork and lamb carcasses were used to assess if it is possible to apply alternative carcass chilling regimes, other than those mandated by current legislation (Reg. (EC) 853/2004) without incurring additional bacterial growth thereby increasing the potential public health risk.

Using the data generated by the modelling exercises it is possible to estimate alternative combinations of carcass surface temperature targets (to be obtained before transportation) with transport time-temperature combinations that result in pathogen growth less or equivalent to that which would be obtained with the current chilling requirements.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

General conclusions

- Bacterial contamination on red meat carcasses occurs primarily on the surface. *Salmonella* spp. and *Y. enterocolitica* are also found in lymph nodes but due to a lack of studies it is unknown if either bacteria multiply in lymphatic tissue during carcass chilling.

- Carcass surface temperature is a more relevant indicator of the effect of chilling on bacterial growth than core temperature.

- The most relevant pathogens when considering the effects of red meat carcass chilling on bacterial growth are *Salmonella* spp., VTEC, *L. monocytogenes*, and *Y. enterocolitica*, based on source, prevalence and association with serious human illness and/or their ability to grow under chill conditions.

- If there is equivalent or less bacterial growth there is no additional risk for consumer. Total bacterial growth is affected by the continuum of chilling in the slaughter plant, during transport, deboning, storage, retail and catering/domestic refrigeration.

- It is possible to have different combinations of slaughterhouse-transportation time-temperature chilling scenarios that result in equivalent or less bacterial growth than that obtained using the currently mandated chilling requirements (chilling to a core temperature of 7 °C in the slaughterhouse chillers before transportation for a maximum of 48 hours).

Reply to the terms of reference

Term of reference 1:

To assess if it is possible to apply alternative core temperatures, higher than 7 °C, in combination with specific transport durations for the transport of meat (carcasses) after the slaughter, without increasing significantly the risk linked to the microbiological growth of potentially harmful microorganisms.

- It is possible to apply alternative carcass chilling regimes for all animal species, other than that mandated by current legislation (Reg. (EC) 853/2004), without incurring additional surface bacterial growth and increasing the potential public health risk.

- Carcasses from all animal species could be transported before the core temperature reaches 7 °C in the slaughterhouse chiller without increasing any food safety risk associated with additional growth of pathogenic bacteria so long as the bacterial growth is controlled by efficient chilling during transportation.

Term of reference 2:

To recommend, if appropriate, in relation to such risk, combinations of a maximum core temperature for the loading of meat (carcasses) and a maximum time for transportation.

- It is possible to calculate surface temperature (for the loading of meat carcasses)-transportation time combinations that would give the equivalent amount of bacterial growth to that which would be obtained with current chilling regimes (as mandated by Reg. (EC) 853/2004). For example, beef carcass chilling to a core temperature of 7 °C and transportation at 4 °C for 48 hours can be replaced with the following alternative time-temperature regimes that provides less or equal growth of pathogens;

a. carcass chilling to a surface temperature of 5 °C (10 h) and transportation at 5 °C for 45 hours;

b. carcass chilling to a surface temperature of 6 °C (9 h) and transportation at 5 °C for 46 hours;

c. carcass chilling to a surface temperature of 6 °C (9 h) and transportation at 6 °C for 37 hours;

d. carcass chilling to a surface temperature of 7 °C (8 h) and transportation at 6 °C for 38 hours;

e. carcass chilling to a surface temperature of 8 °C (7 h) and transportation at 7 °C for 1 hour;

Other equivalent scenarios are also possible.

RECOMMENDATIONS

- Legislative requirements for chilling meat carcasses could be based on an assessment of the surface temperature on the growth of key pathogens such as *Salmonella* spp., VTEC, *L. monocytogenes* and *Y. enterocolitica*.

- Legislation could be defined in terms of process criteria (time-temperature combinations) and/or performance criteria (pathogen growth) and the requirement that these be achieved in the slaughterhouse before carcass loading could be removed if a process of efficient chilling can be demonstrated (including continuous monitoring, corrective actions, etc) during transportation and operated as part of the HACCP or GMP systems at the different stages along the chill chain.

- Data on ambient and carcass surface temperatures in slaughterhouses and during transportation in the European Union should be collected to evaluate current commercial chilling conditions.

- Research should be undertaken to investigate if *Salmonella* spp. can grow in bovine and porcine lymph nodes after slaughter and whether or not *Y. enterocolitica* can multiply in the latter.

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APPENDICES

Appendix A. Baseline scenarios for chilling of beef, lamb and pork

The approaches taken to develop the baseline scenarios are slightly different for the different species due to the type and amount of input data that was available.

1. Beef

Data describing the distribution of initial and final carcass surface temperatures and chilling times (Gill and Landers, 2003), or the frequency of temperatures at the start and after five hours of chilling (Jericho et al., 1998) were used to simulate chilling of beef. Data reflecting maximum time and temperatures during chilling in four slaughterhouses (Gill and Landers, 2003) were also used to develop a "worst case" but still compliant baseline scenario. As described in the approach (Chapter 2), simulated data was fitted to an exponential model to estimate the chilling rate and the initial surface temperature.

The best fit of the exponential equation to simulated data are shown in Figure 1 and fitted parameters and goodness of fit estimates are shown in Table 1. For a comparison with observed data, surface temperatures during the chilling of beef carcasses (using data obtained from a commercial beef slaughterhouse and reviewed by the BIOHAZ Panel) were fitted to the same equation (Figure 1). In addition, observed beef carcass surface temperatures during chilling from a recent Dutch study is included for comparison (TNO, 2013). Comparisons of all temperature profiles based on graphs and fitted parameters shows that the observed data is between the worst case temperature profile based on Gill and Landers (2003) and that based on data from Jericho et al. (Jericho et al., 1998). Thus, these temperature profiles may be used as mean and worst-case scenarios (Figure 1). The fitted parameters in Table 1 were used to develop the chilling temperature profiles for beef baseline scenarios.

Table 19: Parameter and goodness of fit estimates when the exponential decay function was fitted to simulated or observed data. The fitted parameters were used to develop baseline scenarios for chilling of beef. The scenario is defined in terms of, k, the rate of chilling (SE, standard error), and T0 (SE), the initial carcass surface temperature. Five and 95-percentiles and the R2 of the fit are also shown.

K (SE) (hours^{-1})	5-, 95-percentiles	T_0 (SE)	5-, 95-percentiles	R^2	Dataset/comment
0.173 (0.005)	0.181, 0.165	26.3 (0.3)	25.8, 26.7	0.823	(Gill and Landers, 2003) Worst case – based on max time and temperatures
0.069 (0.003)	0.076, 0.063	25.8 (0.3)	25.3, 26.2	0.872	(Gill and Landers, 2003) mean times and temperatures
0.173 (0.018)	0.233, 0.147	18.7 (0.2)	18.4, 19.0	0.931	Jericho et al. average scenario (Jericho et al., 1998)
0.066 (0.001)	0.068. 0.064	19.8 (0.2)	19.4, 20.2	0.900	Beef carcass chilling data (Appendix B) w30/31 – for comparison

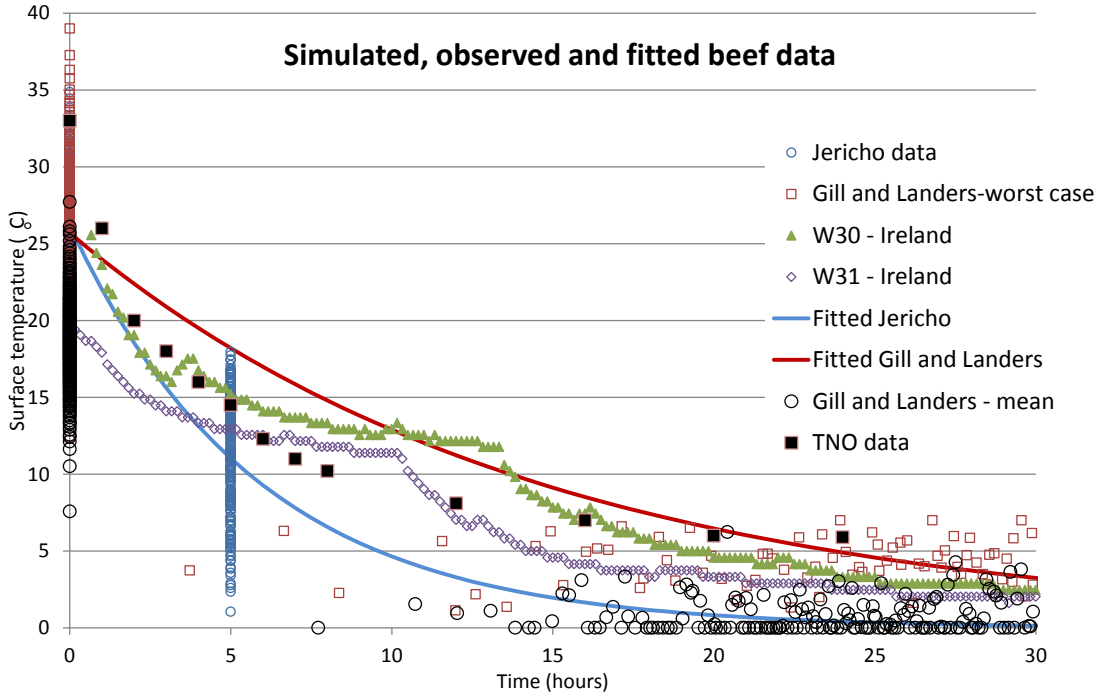

Figure 9: Simulated beef carcass surface temperature data based on Jericho et al. (Jericho et al., 1998), and Gill and Landers (2003), (using mean or maximum temperatures and times), and a comparison with observed Irish (data supplied by the beef industry and reviewed by the BIOHAZ Panel) and Dutch (TNO, 2013) data for carcass chilling. Lines show best fit to the exponential decay function; $T=T_0*e-k*t$, where T, T_0 are temperatures at time t and time zero, and k is the rate coefficient.

Beef baseline scenarios

Based on the comparison in Figure 1 two scenarios were defined; an "average" and a "worst case" case scenario defined by the following equations:

Average: $T= 26.3 * e^{-0.173*t}$
Worst case: $T = 25.8*e^{-0.069*t}$

Time to 7 °C in the core (Based on Irish beef industry data after review by the BIOHAZ Panel):
Mean: 26.6 hours
Median: 27.3 hours
95-percentile: 30.6 hours

2. Lamb

Data describing the distribution of initial and final carcass surface temperatures as well as distribution of chilling times (Gill and Jones, 1997) were used to simulate chilling of lamb. As described in the approach (Chapter 2) simulated data was then fitted to an exponential model to estimate the chilling rate and the initial surface temperature.

Table 20: Parameter and goodness of fit estimates, when the exponential decay function was fitted to simulated or observed data, were developed. The fitted parameters were used to develop baseline scenarios for the chilling of lamb. The scenario is defined in terms of, k, the rate of chilling (SE, standard error), and T_0 (SE), the initial carcass surface temperature. Five and 95-percentiles and the R^2 of the fit are also shown.

K (SE) (hours^{-1})	5, 95	T_0	5, 95	R^2	Dataset/comment
0.111 (0.006)	0.122, 0.102	23.0 (0.2)	22.6, 23.4	0.962	Simulated data based on Gill and Jones (Gill and Jones, 1997)
0.091 (0.003)	0.097, 0.086	26.2 (0.2)	25.9, 26.5	0.982	Simulated worst case (upper quartile) data based on Gill and Jones (Gill and Jones, 1997)
0.192 (0.006)	0.201, 0.182	22.0 (0.4)	21.2, 22.7	0.964	Lamb – thigh (Appendix B)
0.238 (0.007)	0.253, 0.224	19.3 (0.4)	18.6, 20.1	0.962	Lamb – back (Appendix B)

Data reflecting the upper quartiles of simulated temperatures based on the data in Gill and Jones (1997) were used to develop a "worst case" but still compliant baseline scenario. This scenario/model was compared with the fitted model based on all data. There was only a very small difference in the rate of temperature decrease (Table 2). A comparison of chilling based on simulated data with observed data from Norway (Appendix B) also indicate that the rates based on simulated data may be used to represent a worst case (Figure 2). However, the rate equations do not fit very well during extended chilling (>24 hours) and therefore the mean temperature during the period between 24 and 67 hours was used for times greater than 24 hours.

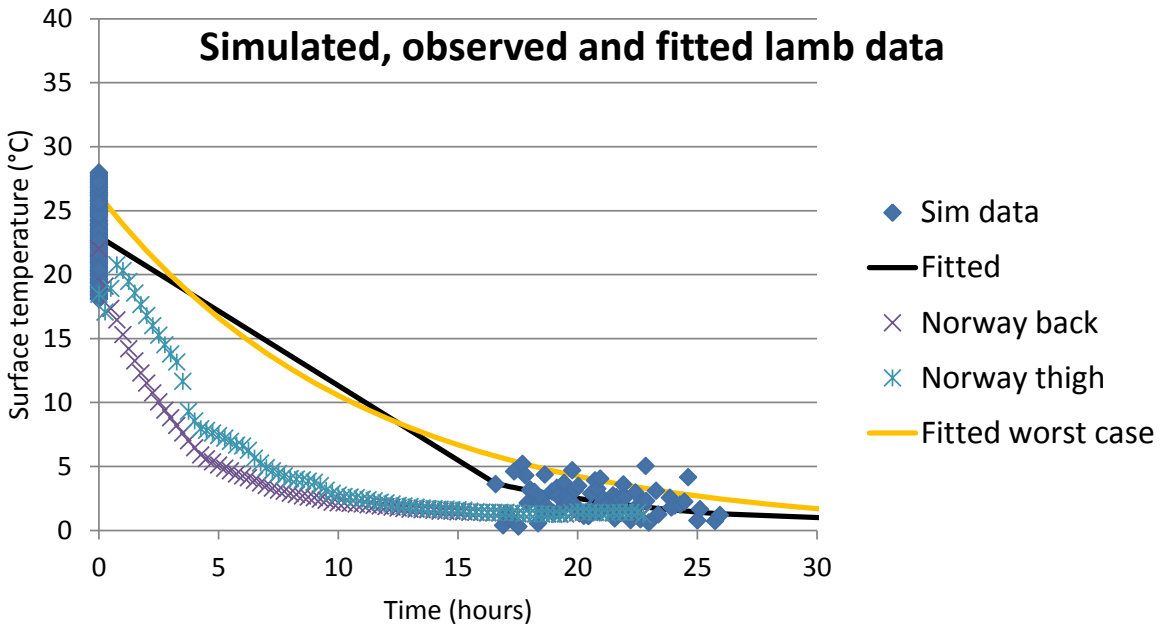

Figure 10: Simulated beef carcass surface temperature data based on Gill and Jones (1997, using all data or the upper quartiles of temperatures=worst case), and a comparison with observed Norwegian data for pork carcass chilling (reviewed by the BIOHAZ Panel before application). Lines show best fit to the exponential decay function; $T=T_0*e-k*t$, where T, T_0 are temperatures at time t and time zero, and k is the rate coefficient.

Lamb baseline scenarios

Based on the comparison in Figure 2 one scenario was defined.

Baseline:
0-24 hours: $T = 26.2*e^{-0.091*t}$
>24 hours: T= 2.3
Time to 7 °C in the core (Assumption based in data in Gill and Jones, 1997): 21.5 hours

3. Pork

A total of 42 surface chilling curves from 5 French slaughterhouses were obtained from Anses (2014). Observed surface temperatures showed a rapid decline followed by a small increase and then after about 5 hours a gradual decline again with a long tail (Figure A3). Consequently, the simple exponential equation could not be used to describe this chilling. The following equation was therefore used to describe the pig baseline scenarios:

$$T = T_a + (T_0 - T_a) * e^{-k*t}$$

Where T_a is the asymptotic final temperature and the other parameters are as described above.

From the 42 chilling curves the mean and the 95-percentile surface temperature was estimated for each measured time interval. The modified exponential equation was fitted to these curves (Figure 3 and table 3).

Table 21: Parameter and goodness of fit estimates when the modified exponential decay function was fitted to the mean or the 95-percentile of the observed data. The fitted parameters were used to develop baseline scenarios for chilling of pigs. The scenario is defined in terms of, k, the rate of chilling (SE, standard error), T_0 (SE), the initial carcass surface temperature, and T_a (SE) the asymptotic final temperature. Five and 95-percentiles and the R^2 of the fit are also shown.

K (SE) (hours^{-1})	K (5, 95-percentile)	T_0	T_0 (5, 95-percentile)	T_a	T_a (5, 95-percentile)	R^2	Dataset/comment
0.105 (0.004)	0.112, 0.099	12.4 (0.2)	12.1, 12.7	4.2(0.1)	4.2, 4.3	0.820	Mean temperatures
0.105 (0.003)	0.110, 0.100	18.3 (0.2)	18.0, 18.6	6.2 (0.1)	6.1, 6.3	0.910	95-percentiles temperatures

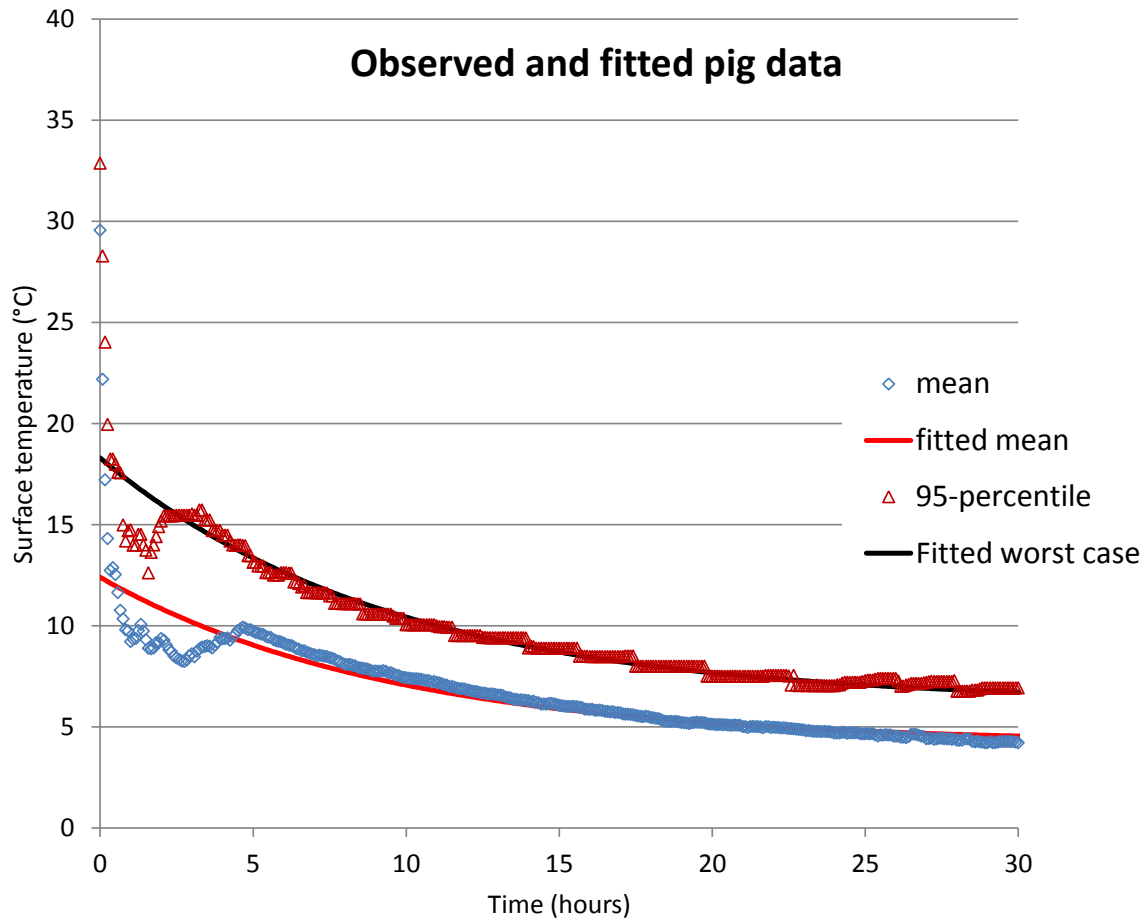

Figure 11: Observed and fitted mean and 95-percentiles (worst case) pig carcass surface temperature based on data from five slaughterhouses. Lines show best fit to the modified exponential decay function; $T=T_a + (T_0-T_a)*e^{-k*t}$, where T, T_0, T_a are temperatures at time t, time zero, final asymptotic temperature and k is the rate coefficient.

Pig baseline scenarios

Based on the results shown in Figure 3 and Table 3 two scenarios were defined; an "average" and a "worst case" case but still compliant case scenario defined by the following equations:

Average: $T = 4.2 + (12.1-4.2)*e^{-0.105*t} = 4.2 + 7.9*e^{-0.105*t}$
Worst case: $T = 6.2 + (18.3-6.2)*e^{-0.105*t} = 6.2 + 12.1*e^{-0.105*t}$
Time to 7 °C in the core (based on Anses (2014)):
Mean: 19.3 hours
Median: 17.8
95-Percentile: 27.5 hours

Appendix B. Chilling data for beef and lamb carcasses

1. Beef carcass chilling data

Week 30

Date (mm/dd/yyyy)	Time	Temp (°C) Deep Round	Temp (°C) Loin/Sirloin	Temp (°C) Surface	Temp (°C) Air
7/23/2013	12:30	16.76	14.47	19.04	18.66
7/23/2013	12:40	10.99	10.99	14.85	11.77
7/23/2013	12:50	9.82	9.82	11.77	10.6
7/23/2013	13:00	39.22	38.32	25.56	9.42
7/23/2013	13:10	39.67	37.88	24.4	10.99
7/23/2013	13:20	39.67	37	23.63	9.82
7/23/2013	13:30	39.22	36.13	22.09	10.99
7/23/2013	13:40	39.22	35.27	21.71	9.42
7/23/2013	13:50	39.22	34.43	20.57	10.99
7/23/2013	14:00	39.22	33.59	20.19	9.42
7/23/2013	14:10	38.77	32.76	19.04	10.99
7/23/2013	14:20	38.77	31.93	19.04	9.42
7/23/2013	14:30	38.32	31.12	17.9	10.6
7/23/2013	14:40	37.88	30.31	17.9	9.42
7/23/2013	14:50	37.88	29.5	17.14	10.6
7/23/2013	15:00	37.44	28.7	16.76	9.03
7/23/2013	15:10	37	28.31	16.38	11.38
7/23/2013	15:20	37	27.52	16.38	9.42
7/23/2013	15:30	36.57	26.73	16	10.99
7/23/2013	15:40	36.13	26.34	16.76	13.32
7/23/2013	15:50	35.7	25.95	17.14	14.09
7/23/2013	16:00	35.27	25.17	17.52	14.47
7/23/2013	16:10	34.85	24.79	17.52	13.32
7/23/2013	16:20	34.85	24.4	16.76	12.55
7/23/2013	16:30	34.43	24.01	16.38	12.16
7/23/2013	16:40	34.01	24.01	16	12.55
7/23/2013	16:50	33.59	23.63	16	11.77
7/23/2013	17:00	33.17	23.24	15.62	12.16
7/23/2013	17:10	32.76	22.86	15.62	11.38
7/23/2013	17:20	32.76	22.48	15.23	11.38
7/23/2013	17:30	32.34	22.09	14.85	11.38
7/23/2013	17:40	31.93	21.71	14.85	11.38
7/23/2013	17:50	31.52	21.71	14.85	11.77
7/23/2013	18:00	31.12	21.33	14.47	11.38
7/23/2013	18:10	30.71	20.95	14.47	11.38
7/23/2013	18:20	30.71	20.57	14.09	10.99
7/23/2013	18:30	30.31	20.57	14.09	11.38
7/23/2013	18:40	29.9	20.19	14.09	12.16
7/23/2013	18:50	29.5	19.81	14.09	11.38
7/23/2013	19:00	29.1	19.42	13.7	10.99
7/23/2013	19:10	29.1	19.42	13.7	10.99
7/23/2013	19:20	28.7	19.04	13.7	11.77
7/23/2013	19:30	28.31	19.04	13.7	10.99
7/23/2013	19:40	27.91	18.66	13.7	11.38
7/23/2013	19:50	27.91	18.28	13.32	11.38

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
7/23/2013	20:00	27.52	18.28	13.32	10.6
7/23/2013	20:10	27.12	17.9	13.32	11.38
7/23/2013	20:20	26.73	17.9	13.32	11.38
7/23/2013	20:30	26.73	17.52	12.93	10.21
7/23/2013	20:40	26.34	17.52	12.93	11.38
7/23/2013	20:50	25.95	17.14	12.93	10.6
7/23/2013	21:00	25.56	17.14	12.93	11.38
7/23/2013	21:10	25.56	16.76	12.93	10.21
7/23/2013	21:20	25.17	16.76	12.55	10.99
7/23/2013	21:30	25.17	16.38	12.93	11.38
7/23/2013	21:40	24.79	16.38	12.55	10.6
7/23/2013	21:50	24.4	16	12.55	11.38
7/23/2013	22:00	24.4	16	12.55	10.99
7/23/2013	22:10	24.01	15.62	12.93	10.99
7/23/2013	22:20	24.01	15.62	12.93	11.38
7/23/2013	22:30	23.63	15.62	13.32	11.38
7/23/2013	22:40	23.24	15.62	12.93	10.6
7/23/2013	22:50	23.24	15.23	12.55	10.21
7/23/2013	23:00	22.86	15.23	12.55	11.38
7/23/2013	23:10	22.86	15.23	12.55	10.6
7/23/2013	23:20	22.48	14.85	12.55	10.21
7/23/2013	23:30	22.48	14.85	12.16	10.99
7/23/2013	23:40	22.48	14.85	12.55	11.38
7/23/2013	23:50	22.09	14.47	12.16	10.21
7/24/2013	00:00	22.09	14.47	12.16	10.21
7/24/2013	00:10	21.71	14.47	12.16	10.6
7/24/2013	00:20	21.71	14.47	12.16	10.99
7/24/2013	00:30	21.33	14.09	12.16	10.99
7/24/2013	00:40	21.33	14.09	12.16	11.38
7/24/2013	00:50	21.33	14.09	12.16	11.38
7/24/2013	01:00	20.95	14.09	12.16	10.6
7/24/2013	01:10	20.95	13.7	11.77	10.21
7/24/2013	01:20	20.57	13.7	11.77	10.21
7/24/2013	01:30	20.57	13.7	11.77	10.21
7/24/2013	01:40	20.57	13.7	11.77	9.03
7/24/2013	01:50	20.19	13.32	10.6	5.81
7/24/2013	02:00	20.19	13.32	10.21	4.57
7/24/2013	02:10	19.81	13.32	9.82	4.15
7/24/2013	02:20	19.81	12.93	9.03	4.15
7/24/2013	02:30	19.81	12.93	9.03	3.74
7/24/2013	02:40	19.42	12.93	8.63	3.74
7/24/2013	02:50	19.42	12.55	8.63	3.31
7/24/2013	03:00	19.04	12.55	8.23	2.89
7/24/2013	03:10	19.04	12.16	8.23	3.47
7/24/2013	03:20	19.04	11.77	7.83	2.89
7/24/2013	03:30	18.66	11.77	7.83	3.31
7/24/2013	03:40	18.66	11.38	7.43	2.89
7/24/2013	03:50	18.28	11.38	7.43	3.74
7/24/2013	04:00	18.28	10.99	7.03	2.89
7/24/2013	04:10	17.9	10.99	7.43	3.74

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
7/24/2013	04:20	17.9	10.6	7.43	4.99
7/24/2013	04:30	17.52	10.21	7.83	5.4
7/24/2013	04:40	17.52	10.21	7.43	3.74
7/24/2013	04:50	17.14	10.21	7.03	3.31
7/24/2013	05:00	17.14	9.82	6.62	2.46
7/24/2013	05:10	16.76	9.82	6.62	3.74
7/24/2013	05:20	16.76	9.42	6.22	2.89
7/24/2013	05:30	16.38	9.42	6.22	3.31
7/24/2013	05:40	16.38	9.42	6.22	2.89
7/24/2013	05:50	16	9.03	6.22	3.74
7/24/2013	06:00	16	9.03	5.81	2.89
7/24/2013	06:10	15.62	8.63	5.81	2.46
7/24/2013	06:20	15.62	8.63	5.81	3.31
7/24/2013	06:30	15.62	8.23	5.4	2.89
7/24/2013	06:40	15.23	8.23	5.4	2.89
7/24/2013	06:50	15.23	7.83	5.4	2.89
7/24/2013	07:00	14.85	7.83	5.4	3.31
7/24/2013	07:10	14.85	7.83	5.4	2.46
7/24/2013	07:20	14.47	7.43	4.99	2.89
7/24/2013	07:30	14.47	7.43	4.99	2.46
7/24/2013	07:40	14.09	7.03	4.99	2.46
7/24/2013	07:50	14.09	7.03	4.99	2.89
7/24/2013	08:00	14.09	7.03	4.99	3.31
7/24/2013	08:10	13.7	7.03	4.99	2.46
7/24/2013	08:20	13.7	6.62	4.57	2.89
7/24/2013	08:30	13.32	6.62	4.57	3.31
7/24/2013	08:40	13.32	6.62	4.57	2.89
7/24/2013	08:50	13.32	6.22	4.57	2.89
7/24/2013	09:00	12.93	6.22	4.57	2.89
7/24/2013	09:10	12.93	6.22	4.57	2.46
7/24/2013	09:20	12.55	6.22	4.57	2.89
7/24/2013	09:30	12.55	5.81	4.57	2.89
7/24/2013	09:40	12.55	5.81	4.15	2.89
7/24/2013	09:50	12.16	5.81	4.15	2.46
7/24/2013	10:00	12.16	5.81	4.15	2.89
7/24/2013	10:10	12.16	5.4	4.15	2.89
7/24/2013	10:20	11.77	5.4	4.57	3.74
7/24/2013	10:30	11.77	5.4	4.57	3.74
7/24/2013	10:40	11.77	5.4	4.57	2.46
7/24/2013	10:50	11.38	5.4	4.15	2.46
7/24/2013	11:00	11.38	5.4	4.15	2.89
7/24/2013	11:10	11.38	4.99	4.15	2.03
7/24/2013	11:20	10.99	4.99	3.74	2.03
7/24/2013	11:30	10.99	4.99	3.74	2.03
7/24/2013	11:40	10.99	4.99	3.74	2.03
7/24/2013	11:50	10.99	4.99	3.74	1.6
7/24/2013	12:00	10.6	4.99	3.74	1.6
7/24/2013	12:10	10.6	4.57	3.31	2.03
7/24/2013	12:20	10.6	4.57	3.31	2.03
7/24/2013	12:30	10.21	4.57	3.31	1.17

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
7/24/2013	12:40	10.21	4.57	3.31	2.03
7/24/2013	12:50	10.21	4.57	3.31	2.03
7/24/2013	13:00	10.21	4.15	3.31	1.6
7/24/2013	13:10	9.82	4.15	3.31	2.03
7/24/2013	13:20	9.82	4.15	3.31	2.03
7/24/2013	13:30	9.82	4.15	2.89	1.17
7/24/2013	13:40	9.82	4.15	2.89	1.6
7/24/2013	13:50	9.42	3.74	2.89	2.46
7/24/2013	14:00	9.42	3.74	2.89	1.6
7/24/2013	14:10	9.42	3.74	2.89	1.6
7/24/2013	14:20	9.42	3.74	2.89	2.03
7/24/2013	14:30	9.03	3.74	2.89	2.03
7/24/2013	14:40	9.03	3.74	2.89	1.6
7/24/2013	14:50	9.03	3.74	2.89	1.6
7/24/2013	15:00	9.03	3.31	2.89	2.03
7/24/2013	15:10	8.63	3.31	2.89	2.03
7/24/2013	15:20	8.63	3.31	2.89	1.17
7/24/2013	15:30	8.63	3.31	2.89	1.6
7/24/2013	15:40	8.63	3.31	2.89	2.03
7/24/2013	15:50	8.23	3.31	2.89	2.03
7/24/2013	16:00	8.23	3.31	2.89	2.03
7/24/2013	16:10	8.23	3.31	2.89	2.03
7/24/2013	16:20	8.23	2.89	2.89	2.46
7/24/2013	16:30	7.83	2.89	2.89	2.89
7/24/2013	16:40	7.83	2.89	2.89	2.03
7/24/2013	16:50	7.83	2.89	2.89	2.46
7/24/2013	17:00	7.83	2.89	2.89	2.03
7/24/2013	17:10	7.83	2.89	2.46	2.03
7/24/2013	17:20	7.83	2.89	2.46	2.03
7/24/2013	17:30	7.43	2.89	2.46	2.03
7/24/2013	17:40	7.43	2.89	2.46	2.03
7/24/2013	17:50	7.43	2.89	2.46	1.17
7/24/2013	18:00	7.43	2.89	2.46	2.03
7/24/2013	18:10	7.43	2.89	2.46	1.6
7/24/2013	18:20	7.03	2.89	2.46	1.6
7/24/2013	18:30	7.03	2.89	2.46	2.03
7/24/2013	18:40	7.03	2.89	2.46	2.03
7/24/2013	18:50	7.03	2.89	2.46	2.03
7/24/2013	19:00	7.03	2.89	2.46	2.46
7/24/2013	19:10	7.03	2.46	2.46	1.6
7/24/2013	19:20	6.62	2.46	2.46	1.6
7/24/2013	19:30	6.62	2.46	2.46	2.03
7/24/2013	19:40	6.62	2.46	2.46	2.03
7/24/2013	19:50	6.62	2.46	2.46	1.6
7/24/2013	20:00	6.62	2.46	2.46	2.03
7/24/2013	20:10	6.62	2.46	2.46	2.03
7/24/2013	20:20	6.22	2.46	2.46	1.17
7/24/2013	20:30	6.22	2.46	2.46	1.6
7/24/2013	20:40	6.22	2.46	2.46	1.6
7/24/2013	20:50	6.22	2.46	2.46	1.6

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
7/24/2013	21:00	6.22	2.46	2.46	2.03
7/24/2013	21:10	6.22	2.46	2.46	2.03
7/24/2013	21:20	6.22	2.46	2.03	1.6
7/24/2013	21:30	6.22	2.46	2.03	2.03
7/24/2013	21:40	5.81	2.46	2.46	1.6
7/24/2013	21:50	5.81	2.46	2.46	2.03
7/24/2013	22:00	5.81	2.46	2.46	2.46
7/24/2013	22:10	5.81	2.46	2.46	1.6
7/24/2013	22:20	5.81	2.46	2.46	1.6
7/24/2013	22:30	5.81	2.46	2.03	1.6
7/24/2013	22:40	5.81	2.03	2.03	1.6
7/24/2013	22:50	5.4	2.03	2.03	1.6
7/24/2013	23:00	5.4	2.03	2.03	1.17
7/24/2013	23:10	5.4	2.03	2.46	2.03
7/24/2013	23:20	5.4	2.03	2.46	2.03
7/24/2013	23:30	5.4	2.03	2.46	2.46
7/24/2013	23:40	5.4	2.03	2.46	2.46
7/24/2013	23:50	5.4	2.03	2.46	2.46
7/25/2013	00:00	5.4	2.03	2.46	2.46
7/25/2013	00:10	5.4	2.03	2.46	2.46
7/25/2013	00:20	5.4	2.03	2.46	2.46
7/25/2013	00:30	4.99	2.03	2.46	2.46
7/25/2013	00:40	4.99	2.03	2.46	2.46
7/25/2013	00:50	4.99	2.03	2.46	2.89
7/25/2013	01:00	4.99	2.03	2.46	2.89
7/25/2013	01:10	4.99	2.03	2.46	2.89
7/25/2013	01:20	4.99	2.03	2.46	2.89
7/25/2013	01:30	4.99	2.03	2.89	2.89
7/25/2013	01:40	4.99	2.03	2.89	2.89
7/25/2013	01:50	4.99	2.03	2.89	2.89
7/25/2013	02:00	4.99	2.03	2.89	2.89
7/25/2013	02:10	4.99	2.46	2.89	2.89
7/25/2013	02:20	4.99	2.46	2.89	2.89
7/25/2013	02:30	4.99	2.46	2.89	2.89
7/25/2013	02:40	4.99	2.46	2.89	2.89
7/25/2013	02:50	4.99	2.46	2.89	2.89
7/25/2013	03:00	4.99	2.46	2.89	2.89
7/25/2013	03:10	4.99	2.46	2.89	2.89
7/25/2013	03:20	4.99	2.46	2.89	2.89
7/25/2013	03:30	4.99	2.46	2.89	2.89
7/25/2013	03:40	4.99	2.46	2.89	3.31
7/25/2013	03:50	4.99	2.46	2.89	3.31
7/25/2013	04:00	4.99	2.46	2.89	3.31
7/25/2013	04:10	4.57	2.46	2.89	3.31
7/25/2013	04:20	4.99	2.46	2.89	3.31
7/25/2013	04:30	4.57	2.46	2.89	3.31
7/25/2013	04:40	4.57	2.46	2.89	3.31
7/25/2013	04:50	4.57	2.46	2.89	3.31
7/25/2013	05:00	4.57	2.46	2.89	3.31
7/25/2013	05:10	4.57	2.46	2.89	3.31

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
7/25/2013	05:20	4.57	2.46	2.89	3.31
7/25/2013	05:30	4.57	2.46	2.89	3.31
7/25/2013	05:40	4.57	2.46	2.89	3.31
7/25/2013	05:50	4.57	2.46	3.31	3.31
7/25/2013	06:00	4.57	2.46	3.31	3.31
7/25/2013	06:10	4.57	2.46	3.31	3.31
7/25/2013	06:20	4.57	2.89	3.31	3.31
7/25/2013	06:30	4.57	2.89	3.31	2.89
7/25/2013	06:40	4.57	2.89	2.89	1.6
7/25/2013	06:50	4.57	2.89	2.89	1.6
7/25/2013	07:00	4.57	2.89	2.89	1.6
7/25/2013	07:10	4.57	2.89	2.89	1.6
7/25/2013	07:20	4.57	2.89	2.46	1.6
7/25/2013	07:30	4.57	2.89	2.46	2.03
7/25/2013	07:40	4.57	2.46	2.46	2.03
7/25/2013	07:50	4.57	2.46	2.46	1.17
7/25/2013	08:00	4.57	2.46	2.46	1.6
7/25/2013	08:10	4.57	2.46	2.46	2.03
7/25/2013	08:20	4.57	2.46	2.46	1.6
7/25/2013	08:30	4.57	2.46	2.46	1.17
7/25/2013	08:40	4.57	2.46	2.46	1.17
7/25/2013	08:50	4.57	2.46	2.03	1.6
7/25/2013	09:00	4.57	2.46	2.03	1.6
7/25/2013	09:10	4.57	2.46	2.03	1.6
7/25/2013	09:20	4.57	2.46	2.03	2.03
7/25/2013	09:30	4.57	2.46	2.03	2.03
7/25/2013	09:40	4.57	2.46	2.03	1.6
7/25/2013	09:50	4.57	2.46	2.03	1.6
7/25/2013	10:00	4.15	2.03	2.03	2.03
7/25/2013	10:10	4.15	2.03	2.46	2.03
7/25/2013	10:20	4.15	2.03	2.46	2.46
7/25/2013	10:30	4.15	2.03	2.03	1.17
7/25/2013	10:40	4.15	2.03	2.03	1.17
7/25/2013	10:50	4.15	2.03	2.03	2.03
7/25/2013	11:00	4.15	2.03	2.03	1.6
7/25/2013	11:10	4.15	2.03	2.03	1.6
7/25/2013	11:20	4.15	2.03	2.03	2.03
7/25/2013	11:30	4.15	2.03	2.03	1.6
7/25/2013	11:40	4.15	2.03	2.03	2.03
7/25/2013	11:50	4.15	2.03	2.03	2.03
7/25/2013	12:00	4.15	2.03	2.03	2.03
7/25/2013	12:10	3.74	2.03	2.03	1.6
7/25/2013	12:20	3.74	2.03	2.03	2.03
7/25/2013	12:30	3.74	2.03	2.03	1.17
7/25/2013	12:40	3.74	2.03	2.03	1.17
7/25/2013	12:50	3.74	2.03	2.03	1.6
7/25/2013	13:00	3.74	2.03	2.03	2.03
7/25/2013	13:10	3.74	2.03	2.03	1.17
7/25/2013	13:20	3.74	2.03	2.03	1.17
7/25/2013	13:30	3.74	2.03	2.03	2.03

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
7/25/2013	13:40	3.74	2.03	2.03	2.46
7/25/2013	13:50	3.74	2.03	2.03	1.6
7/25/2013	14:00	3.74	2.03	2.03	2.03
7/25/2013	14:10	3.74	2.03	1.6	1.17
7/25/2013	14:20	3.74	2.03	1.6	1.6
7/25/2013	14:30	3.74	2.03	1.6	1.6
7/25/2013	14:40	3.74	2.03	1.6	1.6
7/25/2013	14:50	3.74	2.03	1.6	1.17
7/25/2013	15:00	3.74	2.03	1.6	1.6
7/25/2013	15:10	3.31	1.6	2.03	1.17
7/25/2013	15:20	3.31	1.6	2.03	1.6
7/25/2013	15:30	3.31	1.6	2.03	2.03
7/25/2013	15:40	3.31	1.6	1.6	2.03
7/25/2013	15:50	3.31	1.6	1.6	2.03
7/25/2013	16:00	3.31	1.6	2.03	2.03
7/25/2013	16:10	3.31	1.6	2.03	2.03
7/25/2013	16:20	3.31	1.6	2.03	2.03
7/25/2013	16:30	3.31	1.6	2.03	2.03
7/25/2013	16:40	3.31	1.6	2.03	2.03
7/25/2013	16:50	3.31	1.6	2.03	1.6
7/25/2013	17:00	3.31	1.6	2.03	2.03
7/25/2013	17:10	3.31	1.6	2.03	2.03
7/25/2013	17:20	3.31	1.6	2.03	2.03
7/25/2013	17:30	3.31	1.6	2.03	2.03
7/25/2013	17:40	3.31	1.6	2.03	2.03
7/25/2013	17:50	3.31	1.6	2.03	2.03
7/25/2013	18:00	3.31	1.6	2.03	2.03
7/25/2013	18:10	3.31	1.6	2.03	2.03
7/25/2013	18:20	3.31	1.6	2.03	2.46
7/25/2013	18:30	3.31	1.6	2.03	2.46
7/25/2013	18:40	3.31	1.6	2.03	2.46
7/25/2013	18:50	2.89	1.6	2.03	2.46
7/25/2013	19:00	2.89	1.6	2.03	2.46
7/25/2013	19:10	2.89	2.03	2.03	2.46
7/25/2013	19:20	2.89	2.03	2.46	2.89
7/25/2013	19:30	2.89	2.03	2.03	1.6
7/25/2013	19:40	2.89	2.03	2.03	1.6
7/25/2013	19:50	2.89	2.03	2.03	1.17
7/25/2013	20:00	2.89	2.03	2.03	1.17
7/25/2013	20:10	2.89	2.03	2.03	1.6
7/25/2013	20:20	2.89	2.03	2.03	1.6
7/25/2013	20:30	2.89	2.03	2.03	1.6
7/25/2013	20:40	2.89	2.03	2.03	1.6
7/25/2013	20:50	2.89	2.03	2.03	1.6
7/25/2013	21:00	2.89	2.03	2.03	1.6
7/25/2013	21:10	2.89	2.03	2.03	1.6
7/25/2013	21:20	2.89	2.03	2.03	1.17
7/25/2013	21:30	2.89	2.03	2.03	1.17
7/25/2013	21:40	2.89	2.03	2.03	1.17
7/25/2013	21:50	2.89	2.03	2.03	1.17

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
7/25/2013	22:00	2.89	1.6	2.03	2.03
7/25/2013	22:10	2.89	1.6	2.03	2.03
7/25/2013	22:20	2.89	1.6	2.03	2.03
7/25/2013	22:30	2.89	1.6	2.03	2.03
7/25/2013	22:40	2.89	1.6	2.03	2.03
7/25/2013	22:50	2.89	1.6	2.03	2.03
7/25/2013	23:00	2.89	1.6	2.03	2.03
7/25/2013	23:10	2.89	1.6	2.03	2.03
7/25/2013	23:20	2.89	1.6	2.03	2.03
7/25/2013	23:30	2.89	1.6	2.03	2.03
7/25/2013	23:40	2.89	1.6	1.6	2.03
7/25/2013	23:50	2.89	1.6	1.6	1.6
7/26/2013	00:00	2.89	1.6	2.03	2.03
7/26/2013	00:10	2.89	1.6	2.03	2.03
7/26/2013	00:20	2.89	1.6	2.03	2.03
7/26/2013	00:30	2.89	1.6	1.6	2.03
7/26/2013	00:40	2.89	1.6	1.6	2.03
7/26/2013	00:50	2.89	1.6	1.6	2.03
7/26/2013	01:00	2.89	1.6	1.6	2.03
7/26/2013	01:10	2.89	1.6	1.6	1.6
7/26/2013	01:20	2.89	1.6	1.6	1.6
7/26/2013	01:30	2.89	1.6	1.6	1.6
7/26/2013	01:40	2.46	1.6	1.6	1.17
7/26/2013	01:50	2.46	1.6	1.6	1.6
7/26/2013	02:00	2.46	1.6	1.6	2.03
7/26/2013	02:10	2.46	1.6	1.6	2.03
7/26/2013	02:20	2.46	1.6	1.6	1.6
7/26/2013	02:30	2.46	1.6	1.6	1.6
7/26/2013	02:40	2.46	1.6	1.6	1.6
7/26/2013	02:50	2.46	1.6	1.6	1.17
7/26/2013	03:00	2.46	1.6	1.6	2.03
7/26/2013	03:10	2.46	1.6	1.6	2.03
7/26/2013	03:20	2.46	1.6	1.6	1.6
7/26/2013	03:30	2.46	1.6	1.6	1.17
7/26/2013	03:40	2.46	1.6	1.6	2.03
7/26/2013	03:50	2.46	1.6	1.6	2.03
7/26/2013	04:00	2.46	1.6	1.6	1.6
7/26/2013	04:10	2.46	1.6	1.6	1.6
7/26/2013	04:20	2.46	1.6	1.6	1.17
7/26/2013	04:30	2.46	1.6	1.6	2.03
7/26/2013	04:40	2.46	1.6	1.6	2.03
7/26/2013	04:50	2.46	1.6	1.6	1.6
7/26/2013	05:00	2.46	1.6	1.6	1.17
7/26/2013	05:10	2.46	1.6	1.6	1.17
7/26/2013	05:20	2.46	1.6	1.6	2.03
7/26/2013	05:30	2.46	1.6	1.6	2.03
7/26/2013	05:40	2.46	1.6	1.6	1.6
7/26/2013	05:50	2.46	1.6	1.6	1.17
7/26/2013	06:00	2.46	1.6	1.6	1.6
7/26/2013	06:10	2.46	1.6	1.6	1.6

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
7/26/2013	06:20	2.46	1.6	1.6	2.03
7/26/2013	06:30	2.46	1.6	1.6	1.6
7/26/2013	06:40	2.46	1.6	1.6	1.17
7/26/2013	06:50	2.46	1.6	1.6	1.6
7/26/2013	07:00	2.46	1.6	1.6	1.6
7/26/2013	07:10	2.46	1.6	1.6	1.6
7/26/2013	07:20	2.03	1.6	1.6	1.6
7/26/2013	07:30	2.03	1.6	1.6	1.6
7/26/2013	07:40	2.03	1.6	1.6	1.17
7/26/2013	07:50	2.03	1.6	1.6	1.17
7/26/2013	08:00	2.03	1.6	1.6	1.6
7/26/2013	08:10	2.03	1.6	1.6	1.6
7/26/2013	08:20	2.03	1.6	1.6	1.6
7/26/2013	08:30	2.03	1.6	1.6	1.6
7/26/2013	08:40	2.03	1.6	1.6	1.6
7/26/2013	08:50	2.03	1.6	1.6	1.6
7/26/2013	09:00	2.03	1.6	1.6	1.6
7/26/2013	09:10	2.03	1.6	1.6	0.73
7/26/2013	09:20	2.03	1.6	1.6	1.6
7/26/2013	09:30	2.03	1.6	1.6	1.17
7/26/2013	09:40	2.03	1.6	1.6	1.6
7/26/2013	09:50	2.03	1.6	1.6	1.6
7/26/2013	10:00	2.03	1.6	1.6	1.17
7/26/2013	10:10	2.03	1.6	1.6	1.17
7/26/2013	10:20	2.03	1.6	1.6	1.17
7/26/2013	10:30	2.03	1.6	1.6	1.6
7/26/2013	10:40	2.03	1.6	1.6	1.17
7/26/2013	10:50	2.03	1.6	1.6	1.6
7/26/2013	11:00	2.03	1.6	1.6	1.17
7/26/2013	11:10	2.03	1.6	1.6	1.17
7/26/2013	11:20	2.03	1.6	1.6	1.6
7/26/2013	11:30	2.03	1.6	1.6	1.17
7/26/2013	11:40	2.03	1.6	1.6	1.6
7/26/2013	11:50	2.03	1.6	1.6	1.6
7/26/2013	12:00	2.03	1.6	1.6	1.17
7/26/2013	12:10	2.03	1.6	1.6	1.17
7/26/2013	12:20	2.03	1.6	1.6	1.6
7/26/2013	12:30	2.03	1.6	1.6	1.6
7/26/2013	12:40	7.83	7.83	7.83	7.83

Week 31

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
07/30/2013	13:30	25.17	25.56	25.17	25.17
07/30/2013	13:40	39.22	31.52	19.42	9.82
07/30/2013	13:50	39.22	30.71	19.04	12.16
07/30/2013	14:00	39.22	30.31	18.66	12.55
07/30/2013	14:10	38.77	29.5	18.66	12.55
07/30/2013	14:20	38.32	28.7	18.28	10.21
07/30/2013	14:30	38.32	28.31	17.9	10.21

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
07/30/2013	14:40	37.88	27.52	17.14	9.82
07/30/2013	14:50	37.44	27.12	16.76	10.6
07/30/2013	15:00	37	26.34	16.38	10.6
07/30/2013	15:10	37	25.56	16	10.21
07/30/2013	15:20	36.57	25.17	15.62	10.21
07/30/2013	15:30	36.13	24.4	15.23	10.6
07/30/2013	15:40	35.7	24.01	15.23	11.38
07/30/2013	15:50	35.27	23.63	14.85	11.38
07/30/2013	16:00	34.85	22.86	14.85	11.38
07/30/2013	16:10	34.43	22.48	14.47	10.21
07/30/2013	16:20	34.01	22.09	14.47	10.6
07/30/2013	16:30	33.59	21.71	14.09	10.6
07/30/2013	16:40	33.17	21.33	14.09	9.82
07/30/2013	16:50	32.76	20.95	14.09	10.99
07/30/2013	17:00	32.34	20.57	13.7	9.42
07/30/2013	17:10	31.93	20.19	13.7	10.21
07/30/2013	17:20	31.52	20.19	13.7	10.99
07/30/2013	17:30	31.12	19.81	13.32	9.82
07/30/2013	17:40	30.71	19.42	13.32	9.42
07/30/2013	17:50	30.31	19.04	13.32	10.21
07/30/2013	18:00	29.9	19.04	12.93	10.21
07/30/2013	18:10	29.5	18.66	12.93	10.21
07/30/2013	18:20	29.1	18.28	12.93	10.6
07/30/2013	18:30	28.7	18.28	12.93	10.99
07/30/2013	18:40	28.31	17.9	12.93	10.99
07/30/2013	18:50	27.91	17.9	12.55	10.6
07/30/2013	19:00	27.52	17.52	12.55	10.6
07/30/2013	19:10	27.52	17.52	12.55	10.6
07/30/2013	19:20	27.12	17.14	12.55	10.6
07/30/2013	19:30	26.73	17.14	12.55	9.82
07/30/2013	19:40	26.34	16.76	12.16	10.99
07/30/2013	19:50	25.95	16.76	12.16	10.6
07/30/2013	20:00	25.56	16.38	12.16	11.38
07/30/2013	20:10	25.56	16.38	12.55	11.38
07/30/2013	20:20	25.17	16.38	12.55	10.21
07/30/2013	20:30	24.79	16	12.16	9.42
07/30/2013	20:40	24.79	16	12.16	10.21
07/30/2013	20:50	24.4	16	12.16	9.82
07/30/2013	21:00	24.01	15.62	12.16	10.6
07/30/2013	21:10	24.01	15.62	11.77	9.82
07/30/2013	21:20	23.63	15.62	11.77	10.21
07/30/2013	21:30	23.24	15.23	11.77	10.99
07/30/2013	21:40	23.24	15.23	11.77	10.99
07/30/2013	21:50	22.86	15.23	11.77	10.6
07/30/2013	22:00	22.86	14.85	11.77	10.6
07/30/2013	22:10	22.48	14.85	11.77	10.99
07/30/2013	22:20	22.48	14.85	11.38	10.99
07/30/2013	22:30	22.09	14.47	11.38	10.99
07/30/2013	22:40	21.71	14.47	11.38	9.82
07/30/2013	22:50	21.71	14.47	11.38	10.6

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
07/30/2013	23:00	21.33	14.09	11.38	10.99
07/30/2013	23:10	21.33	14.09	11.38	10.21
07/30/2013	23:20	20.95	14.09	11.38	9.42
07/30/2013	23:30	20.95	13.7	11.38	10.21
07/30/2013	23:40	20.57	13.7	11.38	8.63
07/30/2013	23:50	20.57	13.7	10.99	4.57
07/31/2013	00:00	20.19	13.32	10.21	3.74
07/31/2013	00:10	20.19	13.32	9.82	3.74
07/31/2013	00:20	20.19	12.93	9.42	2.46
07/31/2013	00:30	19.81	12.93	9.03	2.89
07/31/2013	00:40	19.81	12.55	8.63	2.46
07/31/2013	00:50	19.42	12.55	8.63	2.46
07/31/2013	01:00	19.42	12.16	8.23	2.89
07/31/2013	01:10	19.04	11.77	7.83	2.89
07/31/2013	01:20	19.04	11.77	7.43	2.03
07/31/2013	01:30	18.66	11.38	7.03	2.46
07/31/2013	01:40	18.66	11.38	7.03	2.46
07/31/2013	01:50	18.28	10.99	6.62	4.57
07/31/2013	02:00	18.28	10.99	6.62	5.81
07/31/2013	02:10	17.9	10.6	7.03	6.22
07/31/2013	02:20	17.52	10.6	7.03	3.31
07/31/2013	02:30	17.52	10.21	6.62	2.46
07/31/2013	02:40	17.14	10.21	6.22	2.03
07/31/2013	02:50	17.14	9.82	6.22	2.46
07/31/2013	03:00	16.76	9.82	5.81	2.46
07/31/2013	03:10	16.76	9.42	5.81	2.89
07/31/2013	03:20	16.38	9.42	5.4	2.46
07/31/2013	03:30	16.38	9.03	5.4	2.46
07/31/2013	03:40	16	9.03	4.99	2.03
07/31/2013	03:50	16	8.63	4.99	2.46
07/31/2013	04:00	15.62	8.63	4.99	2.89
07/31/2013	04:10	15.62	8.23	4.99	2.46
07/31/2013	04:20	15.23	8.23	4.57	2.89
07/31/2013	04:30	15.23	7.83	4.57	2.89
07/31/2013	04:40	14.85	7.83	4.57	2.46
07/31/2013	04:50	14.85	7.83	4.57	2.46
07/31/2013	05:00	14.47	7.43	4.15	2.46
07/31/2013	05:10	14.47	7.43	4.15	2.46
07/31/2013	05:20	14.09	7.03	4.15	2.46
07/31/2013	05:30	14.09	7.03	4.15	2.46
07/31/2013	05:40	14.09	7.03	4.15	2.46
07/31/2013	05:50	13.7	6.62	4.15	2.89
07/31/2013	06:00	13.7	6.62	3.74	2.46
07/31/2013	06:10	13.32	6.62	3.74	2.46
07/31/2013	06:20	13.32	6.22	3.74	2.03
07/31/2013	06:30	12.93	6.22	3.74	2.89
07/31/2013	06:40	12.93	6.22	3.74	2.89
07/31/2013	06:50	12.93	5.81	3.74	2.46
07/31/2013	07:00	12.55	5.81	3.74	2.46
07/31/2013	07:10	12.55	5.81	3.74	2.46

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
07/31/2013	07:20	12.16	5.81	3.74	2.89
07/31/2013	07:30	12.16	5.4	3.31	2.89
07/31/2013	07:40	11.77	5.4	3.31	2.89
07/31/2013	07:50	11.77	5.4	3.74	3.31
07/31/2013	08:00	11.77	5.4	3.74	4.15
07/31/2013	08:10	11.38	5.4	3.74	4.57
07/31/2013	08:20	11.38	4.99	3.74	2.03
07/31/2013	08:30	11.38	4.99	3.74	2.46
07/31/2013	08:40	10.99	4.99	3.74	2.03
07/31/2013	08:50	10.99	4.99	3.74	2.03
07/31/2013	09:00	10.99	4.99	3.74	1.6
07/31/2013	09:10	10.6	4.99	3.31	2.03
07/31/2013	09:20	10.6	4.99	3.31	2.03
07/31/2013	09:30	10.6	4.57	3.31	2.46
07/31/2013	09:40	10.21	4.57	3.31	2.03
07/31/2013	09:50	10.21	4.57	3.31	2.46
07/31/2013	10:00	10.21	4.57	3.31	2.03
07/31/2013	10:10	10.21	4.57	3.31	2.46
07/31/2013	10:20	9.82	4.57	3.31	2.03
07/31/2013	10:30	9.82	4.57	2.89	2.46
07/31/2013	10:40	9.82	4.15	2.89	1.6
07/31/2013	10:50	9.82	4.15	2.89	2.46
07/31/2013	11:00	9.42	4.15	2.89	2.46
07/31/2013	11:10	9.42	4.15	2.89	1.6
07/31/2013	11:20	9.42	4.15	2.89	2.03
07/31/2013	11:30	9.42	4.15	2.89	2.03
07/31/2013	11:40	9.03	3.74	2.89	2.03
07/31/2013	11:50	9.03	3.74	2.89	2.89
07/31/2013	12:00	9.03	3.74	2.89	1.6
07/31/2013	12:10	9.03	3.74	2.89	2.46
07/31/2013	12:20	8.63	3.74	2.89	2.03
07/31/2013	12:30	8.63	3.74	2.89	2.03
07/31/2013	12:40	8.63	3.74	2.89	2.46
07/31/2013	12:50	8.63	3.74	2.89	1.17
07/31/2013	13:00	8.63	3.74	2.89	0.73
07/31/2013	13:10	8.23	3.74	2.46	1.17
07/31/2013	13:20	8.23	3.31	2.46	1.17
07/31/2013	13:30	8.23	3.31	2.46	1.17
07/31/2013	13:40	8.23	3.31	2.46	0.73
07/31/2013	13:50	7.83	3.31	2.46	2.46
07/31/2013	14:00	7.83	3.31	2.46	2.89
07/31/2013	14:10	7.83	3.31	2.46	2.89
07/31/2013	14:20	7.83	3.31	2.46	0.73
07/31/2013	14:30	7.83	3.31	2.46	0.73
07/31/2013	14:40	7.83	3.31	2.46	1.6
07/31/2013	14:50	7.43	3.31	2.46	1.17
07/31/2013	15:00	7.43	2.89	2.46	1.6
07/31/2013	15:10	7.43	2.89	2.03	1.17
07/31/2013	15:20	7.43	2.89	2.03	1.6
07/31/2013	15:30	7.43	2.89	2.03	1.17

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
07/31/2013	15:40	7.03	2.89	2.03	1.17
07/31/2013	15:50	7.03	2.89	2.03	1.17
07/31/2013	16:00	7.03	2.89	2.03	1.6
07/31/2013	16:10	7.03	2.89	2.03	1.17
07/31/2013	16:20	7.03	2.89	2.03	1.6
07/31/2013	16:30	7.03	2.89	2.03	1.17
07/31/2013	16:40	7.03	2.89	2.03	1.6
07/31/2013	16:50	6.62	2.46	2.03	1.6
07/31/2013	17:00	6.62	2.46	2.03	1.6
07/31/2013	17:10	6.62	2.46	2.03	1.17
07/31/2013	17:20	6.62	2.46	2.03	1.6
07/31/2013	17:30	6.62	2.46	2.03	1.6
07/31/2013	17:40	6.22	2.46	2.03	1.6
07/31/2013	17:50	6.22	2.46	2.03	1.6
07/31/2013	18:00	6.22	2.46	2.03	1.6
07/31/2013	18:10	6.22	2.46	2.03	1.17
07/31/2013	18:20	6.22	2.46	2.03	1.6
07/31/2013	18:30	6.22	2.46	2.03	1.17
07/31/2013	18:40	6.22	2.46	1.6	1.6
07/31/2013	18:50	6.22	2.46	2.03	2.03
07/31/2013	19:00	5.81	2.03	2.03	2.46
07/31/2013	19:10	5.81	2.03	2.03	2.46
07/31/2013	19:20	5.81	2.03	2.03	0.73
07/31/2013	19:30	5.81	2.03	2.03	1.6
07/31/2013	19:40	5.81	2.03	2.03	1.17
07/31/2013	19:50	5.81	2.03	2.03	1.6
07/31/2013	20:00	5.81	2.03	2.03	1.6
07/31/2013	20:10	5.4	2.03	2.03	1.17
07/31/2013	20:20	5.4	2.03	1.6	1.6
07/31/2013	20:30	5.4	2.03	1.6	1.17
07/31/2013	20:40	5.4	2.03	1.6	1.6
07/31/2013	20:50	5.4	2.03	1.6	1.6
07/31/2013	21:00	5.4	2.03	1.6	1.6
07/31/2013	21:10	5.4	2.03	1.6	1.17
07/31/2013	21:20	5.4	2.03	1.6	1.17
07/31/2013	21:30	5.4	2.03	1.6	1.6
07/31/2013	21:40	4.99	2.03	1.6	1.17
07/31/2013	21:50	4.99	2.03	1.6	1.6
07/31/2013	22:00	4.99	2.03	1.6	1.6
07/31/2013	22:10	4.99	2.03	1.6	1.6
07/31/2013	22:20	4.99	2.03	1.6	1.17
07/31/2013	22:30	4.99	2.03	1.6	1.17
07/31/2013	22:40	4.99	2.03	1.6	1.6
07/31/2013	22:50	4.99	2.03	1.6	1.17
07/31/2013	23:00	4.99	2.03	1.6	1.6
07/31/2013	23:10	4.99	2.03	1.6	1.6
07/31/2013	23:20	4.57	1.6	1.6	0.73
07/31/2013	23:30	4.57	1.6	1.6	1.17
07/31/2013	23:40	4.57	1.6	1.6	0.73
07/31/2013	23:50	4.57	1.6	1.6	2.03

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
08/01/2013	00:00	4.57	1.6	1.6	1.17
08/01/2013	00:10	4.57	1.6	1.6	1.17
08/01/2013	00:20	4.57	1.6	1.6	1.17
08/01/2013	00:30	4.57	1.6	1.6	1.6
08/01/2013	00:40	4.57	1.6	1.6	1.6
08/01/2013	00:50	4.57	1.6	1.6	1.6
08/01/2013	01:00	4.57	1.6	1.6	2.03
08/01/2013	01:10	4.15	1.6	1.6	2.03
08/01/2013	01:20	4.15	1.6	1.6	0.73
08/01/2013	01:30	4.15	1.6	1.6	1.6
08/01/2013	01:40	4.15	1.6	1.6	0.73
08/01/2013	01:50	4.15	1.6	1.6	2.03
08/01/2013	02:00	4.15	1.6	1.6	1.17
08/01/2013	02:10	4.15	1.6	1.6	1.17
08/01/2013	02:20	4.15	1.6	1.6	2.03
08/01/2013	02:30	4.15	1.6	1.6	1.6
08/01/2013	02:40	4.15	1.6	1.6	1.17
08/01/2013	02:50	4.15	1.6	1.6	1.17
08/01/2013	03:00	4.15	1.6	1.6	1.6
08/01/2013	03:10	3.74	1.6	1.6	1.17
08/01/2013	03:20	3.74	1.6	1.6	1.6
08/01/2013	03:30	3.74	1.6	1.6	0.29
08/01/2013	03:40	3.74	1.6	1.6	0.73
08/01/2013	03:50	3.74	1.6	1.6	1.6
08/01/2013	04:00	3.74	1.6	1.6	1.6
08/01/2013	04:10	3.74	1.6	1.6	1.17
08/01/2013	04:20	3.74	1.6	1.6	1.17
08/01/2013	04:30	3.74	1.6	1.6	1.17
08/01/2013	04:40	3.74	1.6	1.6	1.6
08/01/2013	04:50	3.74	1.6	1.6	1.6
08/01/2013	05:00	3.74	1.6	1.6	1.17
08/01/2013	05:10	3.74	1.6	1.6	2.03
08/01/2013	05:20	3.74	1.6	1.6	1.17
08/01/2013	05:30	3.74	1.6	1.6	1.6
08/01/2013	05:40	3.74	1.6	1.6	1.6
08/01/2013	05:50	3.31	1.6	1.6	1.6
08/01/2013	06:00	3.31	1.6	1.6	1.17
08/01/2013	06:10	3.31	1.6	1.6	1.6
08/01/2013	06:20	3.31	1.6	1.6	1.6
08/01/2013	06:30	3.31	1.6	1.6	1.17
08/01/2013	06:40	3.31	1.6	1.6	1.6
08/01/2013	06:50	3.31	1.6	1.6	1.6
08/01/2013	07:00	3.31	1.6	1.6	2.03
08/01/2013	07:10	3.31	1.6	1.6	2.03
08/01/2013	07:20	3.31	1.6	1.6	0.73
08/01/2013	07:30	3.31	1.6	1.6	1.17
08/01/2013	07:40	3.31	1.6	1.6	1.6
08/01/2013	07:50	3.31	1.6	1.6	1.6
08/01/2013	08:00	3.31	1.6	1.6	1.6
08/01/2013	08:10	3.31	1.6	1.6	1.17

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
08/01/2013	08:20	3.31	1.6	1.6	1.6
08/01/2013	08:30	3.31	1.6	1.6	1.17
08/01/2013	08:40	3.31	1.6	1.6	0.73
08/01/2013	08:50	3.31	1.6	1.6	0.73
08/01/2013	09:00	2.89	1.6	1.6	1.17
08/01/2013	09:10	2.89	1.6	1.6	1.6
08/01/2013	09:20	2.89	1.6	1.6	1.6
08/01/2013	09:30	2.89	1.6	1.6	1.17
08/01/2013	09:40	2.89	1.6	1.6	1.6
08/01/2013	09:50	2.89	1.6	1.6	1.17
08/01/2013	10:00	2.89	1.6	1.6	1.6
08/01/2013	10:10	2.89	1.6	1.6	1.6
08/01/2013	10:20	2.89	1.6	1.6	1.6
08/01/2013	10:30	2.89	1.6	1.6	1.6
08/01/2013	10:40	2.89	1.6	1.6	1.6
08/01/2013	10:50	2.89	1.6	1.6	1.17
08/01/2013	11:00	2.89	1.6	1.6	1.17
08/01/2013	11:10	2.89	1.6	1.6	1.6
08/01/2013	11:20	2.89	1.6	1.6	1.6
08/01/2013	11:30	2.89	1.6	1.6	1.6
08/01/2013	11:40	2.89	1.17	1.6	2.03
08/01/2013	11:50	2.89	1.6	1.6	2.03
08/01/2013	12:00	2.89	1.6	1.6	2.03
08/01/2013	12:10	2.89	1.6	1.6	2.03
08/01/2013	12:20	2.89	1.6	1.6	2.46
08/01/2013	12:30	2.89	1.6	1.6	2.46
08/01/2013	12:40	2.89	1.6	1.6	2.46
08/01/2013	12:50	2.89	1.6	1.6	2.46
08/01/2013	13:00	2.89	1.6	1.6	2.46
08/01/2013	13:10	2.89	1.6	1.6	2.46
08/01/2013	13:20	2.89	1.6	1.6	2.46
08/01/2013	13:30	2.89	1.6	2.03	2.46
08/01/2013	13:40	2.89	1.6	2.03	2.46
08/01/2013	13:50	2.89	1.6	2.03	0.73
08/01/2013	14:00	2.89	1.6	2.03	1.6
08/01/2013	14:10	2.89	1.6	2.03	1.6
08/01/2013	14:20	2.89	1.6	1.6	1.6
08/01/2013	14:30	2.89	1.6	1.6	1.17
08/01/2013	14:40	2.89	1.6	1.6	1.17
08/01/2013	14:50	2.89	1.6	1.6	1.17
08/01/2013	15:00	2.89	1.6	1.6	1.17
08/01/2013	15:10	2.89	1.6	1.6	1.17
08/01/2013	15:20	2.89	1.6	1.6	1.17
08/01/2013	15:30	2.89	1.6	1.6	0.73
08/01/2013	15:40	2.89	1.6	1.6	1.17
08/01/2013	15:50	2.89	1.6	1.6	1.17
08/01/2013	16:00	2.89	1.6	1.6	1.6
08/01/2013	16:10	2.89	1.6	1.6	1.6
08/01/2013	16:20	2.89	1.6	1.6	1.17
08/01/2013	16:30	2.89	1.6	1.6	1.17

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
08/01/2013	16:40	2.89	1.6	1.6	1.17
08/01/2013	16:50	2.89	1.6	1.6	1.17
08/01/2013	17:00	2.89	1.6	1.6	0.73
08/01/2013	17:10	2.89	1.6	1.6	2.03
08/01/2013	17:20	2.89	1.6	1.6	1.17
08/01/2013	17:30	2.89	1.6	1.6	1.17
08/01/2013	17:40	2.46	1.6	1.6	2.03
08/01/2013	17:50	2.46	1.6	1.6	1.6
08/01/2013	18:00	2.46	1.6	1.6	0.73
08/01/2013	18:10	2.46	1.6	1.6	1.17
08/01/2013	18:20	2.46	1.6	1.6	1.6
08/01/2013	18:30	2.46	1.6	1.6	1.6
08/01/2013	18:40	2.46	1.17	1.6	0.73
08/01/2013	18:50	2.46	1.17	1.6	1.6
08/01/2013	19:00	2.46	1.17	1.6	1.6
08/01/2013	19:10	2.46	1.17	1.6	1.6
08/01/2013	19:20	2.46	1.17	1.6	2.03
08/01/2013	19:30	2.46	1.17	1.6	2.03
08/01/2013	19:40	2.46	1.17	1.6	2.03
08/01/2013	19:50	2.46	1.17	1.6	0.29
08/01/2013	20:00	2.46	1.17	1.6	2.03
08/01/2013	20:10	2.46	1.17	1.6	1.6
08/01/2013	20:20	2.46	1.17	1.6	0.73
08/01/2013	20:30	2.46	1.17	1.6	2.03
08/01/2013	20:40	2.46	1.17	1.6	1.17
08/01/2013	20:50	2.46	1.17	1.6	1.17
08/01/2013	21:00	2.46	1.17	1.6	2.03
08/01/2013	21:10	2.46	1.17	1.6	1.17
08/01/2013	21:20	2.46	1.17	1.6	2.03
08/01/2013	21:30	2.46	1.17	1.6	1.6
08/01/2013	21:40	2.46	1.17	1.6	0.73
08/01/2013	21:50	2.46	1.17	1.6	1.6
08/01/2013	22:00	2.46	1.17	1.6	1.17
08/01/2013	22:10	2.46	1.17	1.6	2.03
08/01/2013	22:20	2.46	1.17	1.6	1.17
08/01/2013	22:30	2.46	1.17	1.6	2.03
08/01/2013	22:40	2.46	1.17	1.6	1.17
08/01/2013	22:50	2.46	1.17	1.6	2.03
08/01/2013	23:00	2.46	1.17	1.6	1.17
08/01/2013	23:10	2.46	1.17	1.6	2.03
08/01/2013	23:20	2.46	1.17	1.6	1.17
08/01/2013	23:30	2.46	1.17	1.6	2.03
08/01/2013	23:40	2.03	1.17	1.6	1.17
08/01/2013	23:50	2.03	1.17	1.6	2.03
08/02/2013	00:00	2.03	1.17	1.6	1.17
08/02/2013	00:10	2.03	1.17	1.6	1.6
08/02/2013	00:20	2.03	1.17	1.6	1.6
08/02/2013	00:30	2.03	1.17	1.6	1.6
08/02/2013	00:40	2.03	1.17	1.6	1.6
08/02/2013	00:50	2.03	1.17	1.6	1.6

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
08/02/2013	01:00	2.03	1.17	1.6	1.17
08/02/2013	01:10	2.03	1.17	1.6	1.6
08/02/2013	01:20	2.03	1.17	1.6	1.6
08/02/2013	01:30	2.03	1.17	1.6	1.6
08/02/2013	01:40	2.03	1.17	1.6	2.03
08/02/2013	01:50	2.03	1.17	1.6	0.73
08/02/2013	02:00	2.03	1.17	1.6	1.6
08/02/2013	02:10	2.03	1.17	1.6	1.17
08/02/2013	02:20	2.03	1.17	1.6	2.03
08/02/2013	02:30	2.03	1.17	1.6	1.17
08/02/2013	02:40	2.03	1.17	1.6	1.6
08/02/2013	02:50	2.03	1.17	1.6	0.73
08/02/2013	03:00	2.03	1.17	1.6	1.6
08/02/2013	03:10	2.03	1.17	1.6	0.29
08/02/2013	03:20	2.03	1.17	1.6	1.6
08/02/2013	03:30	2.03	1.17	1.6	0.73
08/02/2013	03:40	2.03	1.17	1.6	1.6
08/02/2013	03:50	2.03	1.17	1.6	2.03
08/02/2013	04:00	2.03	1.17	1.6	1.17
08/02/2013	04:10	2.03	1.17	1.6	2.03
08/02/2013	04:20	2.03	1.17	1.6	1.17
08/02/2013	04:30	2.03	1.17	1.6	2.03
08/02/2013	04:40	2.03	1.17	1.6	1.17
08/02/2013	04:50	2.03	1.17	1.6	1.6
08/02/2013	05:00	2.03	1.17	1.6	0.73
08/02/2013	05:10	2.03	1.17	1.6	1.6
08/02/2013	05:20	2.03	1.17	1.6	0.73
08/02/2013	05:30	2.03	1.17	1.6	1.6
08/02/2013	05:40	2.03	1.17	1.6	0.73
08/02/2013	05:50	2.03	1.17	1.6	1.6
08/02/2013	06:00	2.03	1.17	1.6	0.73
08/02/2013	06:10	2.03	1.17	1.6	1.6
08/02/2013	06:20	2.03	1.17	1.6	1.17
08/02/2013	06:30	2.03	1.17	1.6	1.17
08/02/2013	06:40	2.03	1.17	1.6	1.6
08/02/2013	06:50	2.03	1.17	1.6	1.6
08/02/2013	07:00	2.03	1.17	1.6	1.6
08/02/2013	07:10	2.03	1.17	1.6	1.6
08/02/2013	07:20	2.03	1.17	1.6	2.03
08/02/2013	07:30	2.03	1.17	1.6	2.03
08/02/2013	07:40	2.03	1.17	1.6	2.03
08/02/2013	07:50	2.03	1.17	1.6	2.03
08/02/2013	08:00	2.03	1.17	1.6	2.03
08/02/2013	08:10	2.03	1.17	1.6	2.03
08/02/2013	08:20	2.03	1.6	1.6	2.03
08/02/2013	08:30	2.03	1.6	1.6	2.03
08/02/2013	08:40	2.03	1.6	1.6	2.03
08/02/2013	08:50	2.03	1.6	1.6	2.03
08/02/2013	09:00	2.03	1.6	1.6	2.03
08/02/2013	09:10	2.03	1.6	1.6	2.03

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
08/02/2013	09:20	2.03	1.6	1.6	2.46
08/02/2013	09:30	2.03	1.6	1.6	2.46
08/02/2013	09:40	2.03	1.6	2.03	2.89
08/02/2013	09:50	2.03	1.6	2.03	2.89
08/02/2013	10:00	2.03	1.6	2.03	2.89
08/02/2013	10:10	2.03	1.6	2.03	2.89
08/02/2013	10:20	2.03	1.6	2.03	2.89
08/02/2013	10:30	2.03	1.6	2.46	3.31
08/02/2013	10:40	2.03	1.6	2.46	3.31
08/02/2013	10:50	2.03	2.03	2.46	3.31
08/02/2013	11:00	2.03	2.03	2.46	3.31
08/02/2013	11:10	2.03	2.03	2.89	3.31
08/02/2013	11:20	2.03	2.03	2.89	3.74
08/02/2013	11:30	2.03	2.03	2.89	3.74
08/02/2013	11:40	2.46	2.03	2.89	3.74
08/02/2013	11:50	2.46	2.03	2.89	3.74
08/02/2013	12:00	2.46	2.46	3.31	3.74
08/02/2013	12:10	2.46	2.46	3.31	4.15
08/02/2013	12:20	2.46	2.46	3.31	4.15
08/02/2013	12:30	2.46	2.46	3.74	4.57
08/02/2013	12:40	2.46	2.46	3.74	4.15
08/02/2013	12:50	2.46	2.89	3.74	4.15
08/02/2013	13:00	2.89	2.89	3.74	4.57
08/02/2013	13:10	2.89	2.89	4.15	4.57
08/02/2013	13:20	2.89	2.89	4.15	4.15
08/02/2013	13:30	2.89	2.89	4.15	4.57

Week 32

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
08/07/2013	18:10	10.99	11.38	10.99	11.38
08/07/2013	18:20	25.56	12.93	10.99	8.63
08/07/2013	18:30	25.56	12.93	10.21	7.83
08/07/2013	18:40	25.17	12.55	10.21	10.21
08/07/2013	18:50	25.17	12.55	10.6	11.38
08/07/2013	19:00	24.79	12.55	10.99	8.63
08/07/2013	19:10	24.4	12.16	10.21	9.03
08/07/2013	19:20	24.4	12.16	10.6	10.99
08/07/2013	19:30	24.01	12.16	10.6	11.77
08/07/2013	19:40	24.01	12.16	10.99	7.83
08/07/2013	19:50	23.63	12.16	10.21	9.42
08/07/2013	20:00	23.63	11.77	10.6	10.99
08/07/2013	20:10	23.24	11.77	10.6	11.77
08/07/2013	20:20	23.24	11.77	10.99	7.83
08/07/2013	20:30	22.86	11.77	10.21	9.42
08/07/2013	20:40	22.48	11.77	10.6	10.99
08/07/2013	20:50	22.48	11.38	10.99	11.77
08/07/2013	21:00	22.09	11.38	10.99	12.16
08/07/2013	21:10	22.09	11.38	10.6	8.23
08/07/2013	21:20	21.71	11.38	10.6	10.21

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
08/07/2013	21:30	21.71	11.38	10.6	11.38
08/07/2013	21:40	21.71	11.38	10.99	11.77
08/07/2013	21:50	21.33	11.38	10.99	7.83
08/07/2013	22:00	20.95	11.38	10.6	9.03
08/07/2013	22:10	20.95	11.38	10.21	10.6
08/07/2013	22:20	20.95	10.99	10.6	11.38
08/07/2013	22:30	20.57	10.99	10.99	11.77
08/07/2013	22:40	20.57	10.99	11.38	11.77
08/07/2013	22:50	20.19	10.99	10.6	7.83
08/07/2013	23:00	20.19	10.99	10.6	9.03
08/07/2013	23:10	20.19	10.99	10.6	9.42
08/07/2013	23:20	19.81	10.99	10.6	8.63
08/07/2013	23:30	19.81	10.99	9.42	6.22
08/07/2013	23:40	19.42	10.99	9.42	6.22
08/07/2013	23:50	19.42	10.6	8.23	2.46
08/08/2013	00:00	19.42	10.21	7.03	1.17
08/08/2013	00:10	19.04	10.21	6.22	2.03
08/08/2013	00:20	19.04	9.82	5.81	1.17
08/08/2013	00:30	18.66	9.42	5.4	2.46
08/08/2013	00:40	18.66	9.03	4.99	1.17
08/08/2013	00:50	18.66	8.63	4.57	2.89
08/08/2013	01:00	18.28	8.63	4.15	0.73
08/08/2013	01:10	18.28	8.23	4.15	2.89
08/08/2013	01:20	17.9	7.83	3.74	0.73
08/08/2013	01:30	17.9	7.43	3.74	2.46
08/08/2013	01:40	17.52	7.43	3.74	0.73
08/08/2013	01:50	17.52	7.03	3.31	1.6
08/08/2013	02:00	17.14	6.62	3.31	2.89
08/08/2013	02:10	17.14	6.62	2.89	0.73
08/08/2013	02:20	16.76	6.22	2.89	2.03
08/08/2013	02:30	16.76	6.22	2.89	1.6
08/08/2013	02:40	16.38	5.81	2.89	1.17
08/08/2013	02:50	16.38	5.81	2.89	2.03
08/08/2013	03:00	16.38	5.4	2.89	0.29
08/08/2013	03:10	16	5.4	2.46	1.17
08/08/2013	03:20	16	4.99	2.46	2.46
08/08/2013	03:30	15.62	4.99	2.89	0.73
08/08/2013	03:40	15.62	4.99	2.46	1.17
08/08/2013	03:50	15.23	4.57	2.46	2.03
08/08/2013	04:00	15.23	4.57	2.46	1.17
08/08/2013	04:10	14.85	4.57	2.03	1.17
08/08/2013	04:20	14.85	4.15	2.03	2.03
08/08/2013	04:30	14.47	4.15	2.46	2.89
08/08/2013	04:40	14.47	4.15	2.46	0.29
08/08/2013	04:50	14.47	3.74	2.03	1.17
08/08/2013	05:00	14.09	3.74	2.46	2.46
08/08/2013	05:10	14.09	3.74	2.46	2.89
08/08/2013	05:20	13.7	3.74	2.46	2.89
08/08/2013	05:30	13.7	3.74	2.03	-0.16
08/08/2013	05:40	13.7	3.74	2.03	1.17

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
08/08/2013	05:50	13.32	3.31	2.03	2.03
08/08/2013	06:00	13.32	3.31	2.03	-0.61
08/08/2013	06:10	13.32	3.31	1.6	0.73
08/08/2013	06:20	12.93	3.31	2.03	2.03
08/08/2013	06:30	12.93	2.89	2.03	0.73
08/08/2013	06:40	12.55	2.89	1.6	0.29
08/08/2013	06:50	12.55	2.89	1.6	1.17
08/08/2013	07:00	12.55	2.89	1.6	2.46
08/08/2013	07:10	12.16	2.89	2.03	2.89
08/08/2013	07:20	12.16	2.89	2.03	1.17
08/08/2013	07:30	11.77	2.89	2.03	0.73
08/08/2013	07:40	11.77	2.46	2.03	2.03
08/08/2013	07:50	11.77	2.46	2.03	2.89
08/08/2013	08:00	11.38	2.46	2.03	-0.16
08/08/2013	08:10	11.38	2.46	1.6	0.73
08/08/2013	08:20	11.38	2.46	1.6	1.6
08/08/2013	08:30	10.99	2.46	2.03	2.46
08/08/2013	08:40	10.99	2.46	2.03	3.31
08/08/2013	08:50	10.99	2.46	2.03	-0.16
08/08/2013	09:00	10.6	2.46	1.6	1.17
08/08/2013	09:10	10.6	2.46	1.6	2.03
08/08/2013	09:20	10.6	2.03	2.03	2.89
08/08/2013	09:30	10.21	2.03	2.03	2.46
08/08/2013	09:40	10.21	2.03	2.03	0.29
08/08/2013	09:50	10.21	2.03	1.6	1.6
08/08/2013	10:00	9.82	2.03	2.03	2.46
08/08/2013	10:10	9.82	2.03	2.03	2.89
08/08/2013	10:20	9.82	2.03	2.46	2.89
08/08/2013	10:30	9.42	2.03	2.03	0.73
08/08/2013	10:40	9.42	2.03	2.03	1.6
08/08/2013	10:50	9.42	2.03	2.03	2.03
08/08/2013	11:00	9.42	2.03	2.03	2.46
08/08/2013	11:10	9.03	2.03	2.03	2.46
08/08/2013	11:20	9.03	2.03	2.03	2.46
08/08/2013	11:30	9.03	2.03	2.03	0.73
08/08/2013	11:40	9.03	2.03	1.6	0.73
08/08/2013	11:50	8.63	2.03	1.6	1.6
08/08/2013	12:00	8.63	2.03	1.6	2.46
08/08/2013	12:10	8.63	2.03	2.03	3.31
08/08/2013	12:20	8.63	2.03	2.03	0.29
08/08/2013	12:30	8.23	2.03	1.6	0.73
08/08/2013	12:40	8.23	2.03	1.6	1.6
08/08/2013	12:50	8.23	2.03	1.6	2.46
08/08/2013	13:00	8.23	2.03	2.03	3.31
08/08/2013	13:10	7.83	2.03	2.46	3.31
08/08/2013	13:20	7.83	2.03	2.03	0.29
08/08/2013	13:30	7.83	2.03	2.03	1.6
08/08/2013	13:40	7.83	2.03	2.03	2.46
08/08/2013	13:50	7.83	2.03	2.03	2.89
08/08/2013	14:00	7.43	2.03	2.46	3.74

Date (mm/dd/yyyy)	**Time**	**Temp (°C) Deep Round**	**Temp (°C) Loin/Sirloin**	**Temp (°C) Surface**	**Temp (°C) Air**
08/08/2013	14:10	7.43	2.03	2.46	1.17
08/08/2013	14:20	7.43	2.03	2.03	0.73
08/08/2013	14:30	7.43	2.03	2.03	1.6
08/08/2013	14:40	7.03	2.03	2.03	2.46
08/08/2013	14:50	7.03	2.03	2.03	2.89
08/08/2013	15:00	7.03	2.03	2.03	3.74
08/08/2013	15:10	7.03	2.03	2.46	1.17
08/08/2013	15:20	7.03	2.03	2.46	0.73
08/08/2013	15:30	7.03	2.03	2.03	1.6
08/08/2013	15:40	6.62	2.03	2.03	2.46
08/08/2013	15:50	6.62	2.03	2.03	3.31
08/08/2013	16:00	6.62	2.03	2.03	3.74
08/08/2013	16:10	6.62	2.03	2.46	0.29
08/08/2013	16:20	6.62	2.03	2.03	1.6
08/08/2013	16:30	6.22	2.03	2.03	2.46
08/08/2013	16:40	6.22	2.03	2.03	3.31
08/08/2013	16:50	6.22	2.03	2.03	2.89
08/08/2013	17:00	6.22	2.03	2.46	2.46
08/08/2013	17:10	6.22	2.03	2.46	2.46
08/08/2013	17:20	6.22	2.03	2.46	3.31
08/08/2013	17:30	6.22	2.03	2.46	1.6
08/08/2013	17:40	6.22	2.03	2.46	1.6
08/08/2013	17:50	5.81	2.03	2.46	2.89
08/08/2013	18:00	5.81	2.03	2.46	3.74
08/08/2013	18:10	5.81	2.03	2.89	4.15
08/08/2013	18:20	5.81	2.03	2.89	2.03
08/08/2013	18:30	5.81	2.03	2.46	1.17
08/08/2013	18:40	5.81	2.03	2.46	2.03
08/08/2013	18:50	5.81	2.03	2.46	2.89
08/08/2013	19:00	5.81	2.03	2.89	3.74
08/08/2013	19:10	5.4	2.03	2.89	4.15
08/08/2013	19:20	5.4	2.46	2.89	1.17
08/08/2013	19:30	5.4	2.46	2.46	1.17
08/08/2013	19:40	5.4	2.46	2.46	2.03
08/08/2013	19:50	5.4	2.03	2.46	2.89
08/08/2013	20:00	5.4	2.03	2.46	3.74
08/08/2013	20:10	5.4	2.03	2.89	4.57
08/08/2013	20:20	5.4	2.46	2.89	2.89
08/08/2013	20:30	5.4	2.46	2.89	1.17
08/08/2013	20:40	4.99	2.46	2.46	2.03
08/08/2013	20:50	4.99	2.46	2.46	2.89
08/08/2013	21:00	4.99	2.46	2.89	3.74
08/08/2013	21:10	4.99	2.46	2.89	4.15
08/08/2013	21:20	4.99	2.46	3.31	1.6
08/08/2013	21:30	4.99	2.46	2.89	1.17
08/08/2013	21:40	4.99	2.46	2.46	1.6
08/08/2013	21:50	4.99	2.46	2.46	2.46
08/08/2013	22:00	4.99	2.46	2.46	2.89
08/08/2013	22:10	4.99	2.46	2.46	3.31
08/08/2013	22:20	4.99	2.46	2.46	1.17

Date (mm/dd/yyyy)	Time	Temp (°C) Deep Round	Temp (°C) Loin/Sirloin	Temp (°C) Surface	Temp (°C) Air
08/08/2013	22:30	4.57	2.46	2.03	0.29
08/08/2013	22:40	4.57	2.46	2.03	1.17
08/08/2013	22:50	4.57	2.03	2.03	1.6
08/08/2013	23:00	4.57	2.03	2.03	1.6
08/08/2013	23:10	4.57	2.03	2.03	2.03
08/08/2013	23:20	4.57	2.03	2.03	2.03
08/08/2013	23:30	4.57	2.03	1.6	-0.16
08/08/2013	23:40	4.57	2.03	1.6	0.29
08/08/2013	23:50	4.57	2.03	1.17	1.17
08/09/2013	00:00	4.57	2.03	1.6	2.03
09/09/2013	00:10	4.57	2.03	1.6	2.46
09/09/2013	00:20	4.57	2.03	2.03	2.89
09/09/2013	00:30	4.15	2.03	2.03	1.17
09/09/2013	00:40	4.15	2.03	1.6	0.29
09/09/2013	00:50	4.15	2.03	1.6	1.17
09/09/2013	01:00	4.15	1.6	1.6	1.6
09/09/2013	01:10	4.15	1.6	1.6	2.46
09/09/2013	01:20	4.15	1.6	2.03	2.89
09/09/2013	01:30	4.15	1.6	2.03	3.31
09/09/2013	01:40	4.15	1.6	2.46	2.89
09/09/2013	01:50	4.15	2.03	2.03	0.73

2. Lamb carcass chilling data

Date (dd/mm/yyyy)	Time	Surface temp (°C) back	Surface temp (°C) thigh
06/11/2001	10:55:56	22.0	18.5
06/11/2001	11:10:56	19.1	17.1
06/11/2001	11:25:56	17.4	18.9
06/11/2001	11:40:56	16.5	20.8
06/11/2001	11:55:56	15.3	20.3
06/11/2001	12:10:56	14.2	19.5
06/11/2001	12:25:56	13.3	18.6
06/11/2001	12:40:56	12.3	17.7
06/11/2001	12:55:56	11.5	16.8
06/11/2001	13:10:56	10.8	16.0
06/11/2001	13:25:56	10.1	15.3
06/11/2001	13:40:56	9.4	14.5
06/11/2001	13:55:56	8.8	13.8
06/11/2001	14:10:56	8.2	13.2
06/11/2001	14:25:56	7.6	11.7
06/11/2001	14:40:56	7.0	9.3
06/11/2001	14:55:56	6.5	8.6
06/11/2001	15:10:56	5.9	8.0
06/11/2001	15:25:56	5.6	7.8
06/11/2001	15:40:56	5.4	7.6
06/11/2001	15:55:56	5.1	7.4
06/11/2001	16:10:56	4.9	7.2
06/11/2001	16:25:56	4.7	7.0

Date (dd/mm/yyyy)	**Time**	**Surface temp (°C) back**	**Surface temp (°C) thigh**
06/11/2001	16:40:56	4.4	6.7
06/11/2001	16:55:56	4.3	6.6
06/11/2001	17:10:56	4.1	6.3
06/11/2001	17:25:56	3.9	5.7
06/11/2001	17:40:56	3.7	5.3
06/11/2001	17:55:56	3.5	4.9
06/11/2001	18:10:56	3.3	4.7
06/11/2001	18:25:56	3.2	4.5
06/11/2001	18:40:56	3.1	4.3
06/11/2001	18:55:56	2.9	4.1
06/11/2001	19:10:56	2.8	4.0
06/11/2001	19:25:56	2.7	4.0
06/11/2001	19:40:56	2.6	3.9
06/11/2001	19:55:56	2.6	3.8
06/11/2001	20:10:56	2.5	3.5
06/11/2001	20:25:56	2.4	3.2
06/11/2001	20:40:56	2.2	2.9
06/11/2001	20:55:56	2.2	2.8
06/11/2001	21:10:56	2.2	2.7
06/11/2001	21:25:56	2.1	2.6
06/11/2001	21:40:56	2.1	2.6
06/11/2001	21:55:56	2.1	2.5
06/11/2001	22:10:56	2.0	2.4
06/11/2001	22:25:56	2.0	2.3
06/11/2001	22:40:56	1.9	2.2
06/11/2001	22:55:56	1.9	2.2
06/11/2001	23:10:56	1.8	2.1
06/11/2001	23:25:56	1.8	2.0
06/11/2001	23:40:56	1.7	1.9
06/11/2001	23:55:56	1.7	1.9
07/11/2001	00:10:56	1.7	1.8
07/11/2001	00:25:56	1.6	1.8
07/11/2001	00:40:56	1.6	1.7
07/11/2001	00:55:56	1.6	1.7
07/11/2001	01:10:56	1.5	1.7
07/11/2001	01:25:56	1.5	1.7
07/11/2001	01:40:56	1.5	1.6
07/11/2001	01:55:56	1.5	1.6
07/11/2001	02:10:56	1.5	1.6
07/11/2001	02:25:56	1.4	1.5
07/11/2001	02:40:56	1.4	1.5
07/11/2001	02:55:56	1.4	1.4
07/11/2001	03:10:56	1.4	1.4
07/11/2001	03:25:56	1.4	1.4
07/11/2001	03:40:56	1.4	1.4
07/11/2001	03:55:56	1.4	1.4
07/11/2001	04:10:56	1.3	1.4
07/11/2001	04:25:56	1.3	1.4
07/11/2001	04:40:56	1.3	1.3
07/11/2001	04:55:56	1.3	1.3

Date (dd/mm/yyyy)	**Time**	**Surface temp (°C) back**	**Surface temp (°C) thigh**
07/11/2001	05:10:56	1.3	1.3
07/11/2001	05:25:56	1.3	1.3
07/11/2001	05:40:56	1.3	1.3
07/11/2001	05:55:56	1.3	1.3
07/11/2001	06:10:56	1.3	1.3
07/11/2001	06:25:56	1.3	1.3
07/11/2001	06:40:56	1.3	1.4
07/11/2001	06:55:56	1.4	1.5
07/11/2001	07:10:56	1.4	1.5
07/11/2001	07:25:56	1.4	1.4
07/11/2001	07:40:56	1.4	1.4
07/11/2001	07:55:56	1.4	1.4
07/11/2001	08:10:56	1.4	1.4
07/11/2001	08:25:56	1.4	1.4
07/11/2001	08:40:56	1.4	1.4
07/11/2001	08:55:56	1.4	1.4
07/11/2001	09:10:56	1.4	1.4
07/11/2001	09:25:56	1.4	1.4
07/11/2001	09:40:56	1.3	1.2

Appendix C. Secondary models

For *Escherichia coli* the square root model developed by Ross et al., (2003) was used.

The model equation was:

$$\sqrt{\mu_{max}} = c \bullet (T-T_{min}) \bullet (1-\exp(d \bullet (T-T_{max}))) \bullet \sqrt{(a_w-a_{wmin})} \bullet \sqrt{(1-10^{(pHmin-pH)})} \bullet \sqrt{(1-10^{(pH-pHmax)})} \bullet \sqrt{(1-[LAC]/(U_{min} \bullet (1+10^{(pH-pKa)})))} \bullet \sqrt{(1-[LAC]/(D_{min} \bullet (1+10^{(pKa-pH)})))} \pm e$$

Where:

μ_{max}	= maximum specific growth rate (hours^{-1})
c, d and **g**	= fitted parameters
a_w	= water activity
a_{wmin}	= theoretical minimum water activity below which growth is not possible
T	= temperature,
T_{min}	= theoretical minimum temperature below which growth is not possible
T_{max}	= theoretical maximum temperature beyond which growth is not possible
pH	has its usual meaning
pH_{min}	= theoretical minimum pH below which growth is not possible
pH_{max}	= theoretical maximum pH beyond which growth is not possible
[LAC]	= lactic acid concentration (mM)
U_{min}	= minimum concentration (mM) of undissociated lactic acid which prevents growth when all other factors are optimal
D_{min}	= minimum concentration (mM) of dissociated lactic acid which prevents growth when all other factors are optimal
pKa	is the pH for which concentrations of undissociated and dissociated lactic acid are equal, reported to be 3.86
e	= error

The values of the parameters are:

Parameter	Estimate
C	0.2790
T_{min}	4.14
T_{max}	49.55
pH_{min}	3.909
pH_{max}	8.860
U_{min}	10.43
D_{min}	995.5
a_{wmin}	0.9508
d	0.2636
Root Mean Square Error (RMSE)	0.0054

For *Salmonella* spp., *Listeria monocytogenes* and *Yersinia enterocolitica* the polynomial models of ComBase were used.

The model equation was:

$$Ln(\mu_{max}) = a\_0 + a\_1*T + a\_2*pH + a\_3*bw + a\_4*T*pH + a\_5*T*bw + a\_6*pH*bw + a\_7*tT\text{^}2 + a\_8*pH\text{^}2 + a\_9*bw\text{^}2 + LA*(a\_10 + a\_11*T + a\_12*pH + a\_13*bw + a\_14*LA) \pm e$$

Where:

μ_{max}	= maximum specific growth rate (hours^{-1})
a_0-a_14	= fitted parameters
bw	= sqrt(1-aw), $\mathbf{a_w}$ = water activity
T	= temperature,
pH	has its usual meaning
LA	= Lactic acid concentration (ppm)
e	= error

The values of the parameters are:

Parameter	*Listeria monocytogenes*	*Salmonella* spp.	*Yersinia enterocolitica*
a_0	-18.851	-11.906	-13.616
a_1	0.2409	0.3649	0.203
a_2	4.2628	1.7832	3.0026
a_3	6.36771	7.00019	8.42249
a_4	0	-0.00442	-0.00629
a_5	0	0	0.11391
a_6	0	0	0
a_7	-0.00332	-0.00458	-0.00217
a_8	-0.31377	-0.12539	-0.2171
a_9	-43.1241	-62.114	-93.4381
a_10	-3.5E-05	0	0
a_11	-3E-07	0	0
a_12	0.000009	0	0
a_13	-0.00014	0	0
a_14	-1.2E-09	0	0

Appendix D. Equivalent growth in beef, pork and lamb

Equivalent growth in beef

Table 1: Transportation time required to achieve an equivalent growth of *E. coli* (VTEC) as compared to the mean and worst case baseline scenario for beef carcasses

Target surface temperature achieved during carcass chilling	Surface temperature during transportation					
	5 °C	6 °C	7 °C	8 °C	9 °C	10 °C
	Growth rate (log cfu/cm2/h)					
	0.000	0.000	0.008	0.014	0.022	0.032
	Transportation time (hours) required for the equivalent growth of *E. coli* to mean baseline scenario:					
5 °C	ng	ng				
6 °C	ng	ng	0.0			
7 °C		ng	0.0	0.0		
8 °C			1.3	0.7	0.5	
9 °C				1.4	0.9	0.6
10 °C					1.8	1.2
	Transportation time (hours) required for the equivalent growth of *E. coli* to worst baseline scenario					
5 °C	ng	ng				
6 °C	ng	ng	48.0			
7 °C		ng	48.0	26.4		
8 °C			49.3	27.1	17.1	
9 °C				29.2	18.4	12.7
10 °C					20.2	13.9

Table 2: Transportation time required to achieve an equivalent growth of *L. monocytogenes* as compared to the mean and worst case baseline scenario for beef carcasses

Target surface temperature achieved during carcass chilling	Surface temperature during transportation					
	5 °C	6 °C	7 °C	8 °C	9 °C	10 °C
	Growth rate (log cfu/cm2/h)					
	0.021	0.026	0.031	0.038	0.046	0.054
	Transportation time (hours) required for the equivalent growth of *L. monocytogenes* to mean baseline scenario:					
5 °C	44.6	36.4				
6 °C	45.6	37.2	30.6			
7 °C		38.0	31.2	25.8		
8 °C			32.2	26.6	22.2	
9 °C				27.1	22.6	18.9
10 °C					23.5	19.7
	Transportation time (hours) required for the equivalent growth of *L. monocytogenes* to worst baseline scenario					
5 °C	74.4	60.7				
6 °C	77.3	63.1	51.8			
7 °C		65.4	53.7	44.4		
8 °C			56.0	46.3	38.5	
9 °C				48.1	40.1	33.6
10 °C					41.8	35.1

ng: no growth at this transportation temperature

Equivalent growth in pork

Table 3: Transportation time required to achieve an equivalent growth of *L. monocytogenes* as compared to the mean and worst case baseline scenario for pork carcasses

Target surface temperature achieved during carcass chilling	Surface temperature during transportation					
	5 °C	6 °C	7 °C	8 °C	9 °C	10 °C
	Growth rate (log cfu/cm2/h)					
	0.021	0.026	0.031	0.038	0.046	0.054
	Transportation time (hours) required for the equivalent growth of *L. monocytogenes* to mean baseline scenario:					
5 °C	59.8	48.8				
6 °C	60.3	49.2	40.4			
7 °C		50.0	41.1	34.0		
8 °C			42.0	34.8	29.0	
9 °C				35.8	29.8	25.0
10 °C					30.7	25.7
	Transportation time (hours) required for the equivalent growth of *L. monocytogenes* to worst baseline scenario					
5 °C						
6 °C						
7 °C		60.0	49.3	40.8		
8 °C			57.9	47.9	39.9	
9 °C				52.6	43.8	36.7
10 °C					47.1	39.5

ng: no growth at this transportation temperature

Table 4: Transportation time required to achieve an equivalent growth of *Y. enterocolitica* as compared to the mean and worst case baseline scenario for pork carcasses

Target surface temperature achieved during carcass chilling	Surface temperature during transportation					
	5 °C	6 °C	7 °C	8 °C	9 °C	10 °C
	Growth rate (log cfu/cm2/h)					
	0.039	0.045	0.052	0.060	0.068	0.078
	Transportation time (hours) required for the equivalent growth of *Y. enterocolitica* to mean baseline scenario:					
5 °C	41.2	35.6				
6 °C	46.6	40.2	34.9			
7 °C		44.9	38.9	33.9		
8 °C			42.0	36.5	31.9	
9 °C				38.9	34.0	29.8
10 °C					35.9	31.5
	Transportation time (hours) required for the equivalent growth of *Y. enterocolitica* to worst baseline scenario					
5 °C						
6 °C						
7 °C		57.0	49.4	42.9		
8 °C			57.6	50.2	43.8	
9 °C				54.7	47.8	42.0
10 °C					51.0	44.8

ng: no growth at this transportation temperature

Equivalent growth in lamb

Table 5: Transportation time required to achieve an equivalent growth of *E. coli* as compared to the worst case baseline scenario for lamb carcasses

Target surface temperature achieved during carcass chilling	Surface temperature during transportation					
	5 °C	6 °C	7 °C	8 °C	9 °C	10 °C
	Growth rate (log cfu/cm2/h)					
	0.000	0.000	0.008	0.014	0.022	0.032
	Transportation time (hours) required for the equivalent growth of *E. coli* to worst baseline scenario:					
5 °C	ng	ng				
6 °C	ng	ng	48.0			
7 °C		ng	49.3	27.1		
8 °C			50.6	27.8	17.5	
9 °C				29.2	18.4	12.7
10 °C					19.8	13.6

ng: no growth at this transportation temperature

Table 6: Transportation time required to achieve an equivalent growth of *L. monocytogenes* as compared to the worst case baseline scenario for lamb carcasses

Target surface temperature achieved during carcass chilling	Surface temperature during transportation					
	5 °C	6 °C	7 °C	8 °C	9 °C	10 °C
	Growth rate (log cfu/cm2/h)					
	0.021	0.026	0.031	0.038	0.046	0.054
	Transportation time (hours) required for the equivalent growth of *L. monocytogenes* to worst baseline scenario:					
5 °C	74.4	60.7				
6 °C	76.8	62.7	51.5			
7 °C		64.2	52.8	43.7		
8 °C			54.7	45.2	37.7	
9 °C				46.6	38.8	32.5
10 °C					39.6	33.2

ng: no growth at this transportation temperature

Combined results for all tested pathogens in pork

Table 7: Combinations of surface temperature of pork carcasses at the end of chilling process and maximum transportation time at 5 °C that achieve less or equivalent growth of all tested pathogens as compared to the mean and worst case baseline scenario.

	Carcass surface temperature at the end of chilling (°C)	Maximum transportation time (hours)
Mean baseline scenario	-	
	5	41.2
	6	46.6
Worst case baseline scenario	-	-
	-	-
	-	-

Table 8: Combinations of surface temperature of pork carcasses at the end of chilling process and maximum transportation time at 6 °C that achieve less or equivalent growth of all tested pathogens as compared to the mean and worst case baseline scenario.

	Carcass surface temperature at the end of chilling (°C)	Maximum transportation time (hours)
Mean baseline scenario	5	35.6
	6	40.2
	7	44.9
Worst case baseline scenario	5	-
	6	-
	7	57.0

Table 9: Combinations of surface temperature of pork carcasses at the end of chilling process and maximum transportation time at 7 °C that achieve less or equivalent growth of all tested pathogens as compared to the mean and worst case baseline scenario.

	Carcass surface temperature at the end of chilling (°C)	Maximum transportation time (hours)
Mean baseline scenario	6	0.0
	7	0.0
	8	1.3
Worst case baseline scenario	6	-
	7	48.7
	8	50.7